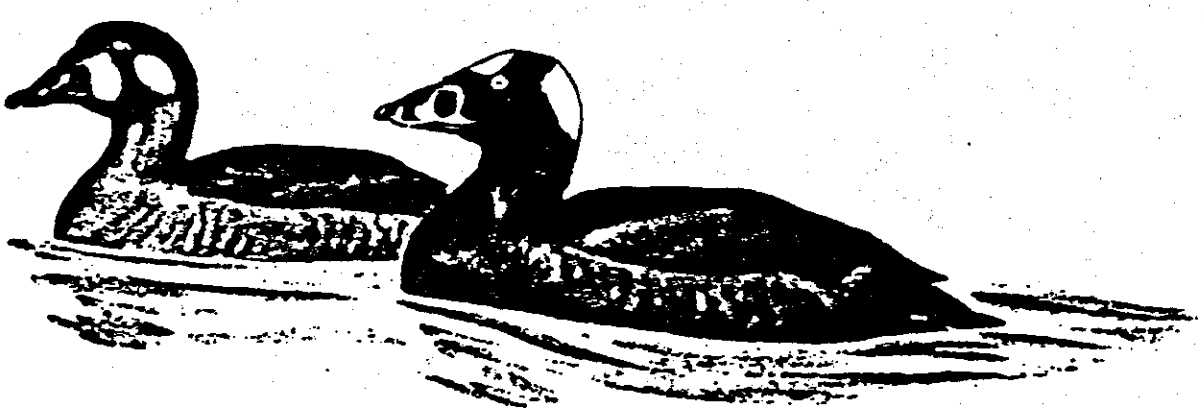
SELENIUM VERIFICATION STUDY 1987 - 1988

A REPORT TO THE

STATE WATER RESOURCES CONTROL BOARD



STATE OF CALIFORNIA

THE RESOURCES AGENCY

DEPARTMENT OF FISH AND GAME

APRIL 1989

SELENIUM VERIFICATION STUDY[1/]

1987-1988

A REPORT TO THE
CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

FROM THE
CALIFORNIA DEPARTMENT OF FISH AND GAME[2/]

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1/ Selenium and Other Trace Element Studies in California: Element 2

2/ Work performed under Interagency Agreement 7-017-300-0.

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Finally, we thank those other contributors whom we inadvertently failed to acknowledge by name.

SUMMARY OF FINDINGS

This report covers findings by the Selenium Verification Study from September 1987 through May 1988. This program represents a continuation of a statewide investigation of selenium in fish and wildlife begun in January 1986. Efforts in 1987-1988 concentrated on Suisun and San Pablo bays, the Sacramento-San Joaquin Delta, the lower San Joaquin River, and four agricultural drainwater evaporation ponds in the southern San Joaquin Valley.

Consistent with previous findings, diving ducks wintering on Suisun and San Pablo bays had higher selenium concentrations than were measured in their counterparts from Humboldt Bay. Selenium levels in surf scoter tissues increased up to two fold during the winter months when these migratory birds were using Suisun and San Pablo bays. This increase was most pronounced for Suisun Bay scoters which had selenium levels higher, on average, in both muscle and liver tissues than scoters from San Pablo Bay. Female scoters had higher levels of selenium in muscle tissue than males, but no difference was observed in liver tissue. Scaup from Suisun Bay also had higher levels of selenium in liver tissue than their counterparts collected on San Pablo Bay, but there was no difference in muscle tissue levels.

Selenium levels in the tissues of scaup and scoters from both bays were significantly higher in late winter 1988 than in the same period of 1986. Levels measured in 1987 were intermediate and not always significantly different from those in 1986 or 1988. This limited data from only three years suggests that diving ducks wintering on Suisun and San Pablo bays may have accumulated selenium to progressively higher levels each year since 1986.

Though our efforts have been limited, we have not observed any biological effects of selenium on diving ducks wintering in California, and because they breed in Canada and Alaska, potential reproductive impacts have not been studied. Histopathological examination of tissues of diving ducks from Suisun and San Pablo bays revealed no abnormal conditions attributable to selenium even though those birds with the highest levels of selenium in their tissues were chosen for examination. Observations were compatible with those expected in ducks exposed to a normal environment.

Diving ducks in Suisun Bay accumulated selenium, on a dry weight basis, up to 1,200,000 times the concentration of total selenium dissolved in bay water. Filter-feeding clams commonly eaten by these ducks contained, on a dry weight basis, 3,000-30,000 times the waterborne selenium level and diving ducks had 6 to 200 times higher levels than clams, depending on duck species and tissue type. Bioaccumulation factors measured

in 1987-88 were greater than those in 1986-87, but due to our small sample size we cannot be sure whether these differences are significant. Bioaccumulation of selenium from water by plankton may account for much of the concentration difference between water and clams which filter plankton from the water.

Striped bass from the Sacramento-San Joaquin Estuary contained lower selenium levels in spring 1988 than in spring 1987, but higher than in spring 1986. Although bass from the Delta have higher selenium levels than an inland population from Success Lake, levels measured in all three years are at or below the median level measured for fish tissue nationwide. There is no direct evidence that selenium has had an impact on striped bass in the estuary and current concentrations in fish tissues are below the level of concern (2 ppm, wet wt.) established by the State Department of Health Services.

White sturgeon selenium concentrations increased significantly from spring 1986 to spring 1987, however, concentrations were lower in spring 1988 than in either preceeding year, indicating no trend for selenium in white sturgeon.

White catfish and channel catfish from Mud Slough and Salt Slough had higher selenium levels than catfish from two sites downstream in the San Joaquin River or from one site upstream of their input, but levels were highest in catfish from Camp 13 Ditch, a channel used for irrigation and drainage in the south Grasslands area. The concentration of selenium in samples of filtered water, suspended particulates, plankton, and sediment (taken concurrently with the fish) generally followed the same pattern. With the exception of fish collected from Camp 13 Ditch, selenium levels in catfish were usually lower in May 1988 than in preceeding months, suggesting that selenium levels in the biota may change seasonally. Selenium levels in catfish are substantially elevated in the tributary sloughs and Camp 13 Ditch but have still not reached levels known to be of concern for the health of fish populations. Selenium concentrations in catfish muscle tissue are below the level of concern established by the State Department of Health Services.

Selenium was measured in ruddy duck tissue and various lower trophic levels of the aquatic ecosystem of four southern San Joaquin Valley agricultural drainage water evaporation pond systems. Selenium levels in duck tissues, invertebrates, and plankton were lowest in the pond system with the lowest concentrations of dissolved selenium. However, selenium concentrations were not consistent between trophic levels in the other three pond systems with higher levels of dissolved selenium. Selenium levels in ruddy duck liver averaged from 12 to 59 ppm (dry wt.) and from 4.2 to 22 ppm (dry wt.) in muscle tissue at the four sites. Bioaccumulation of selenium was greatest at the lowest trophic level (particulates (ppm, dry wt.) = 13-6,000 x water (ppb)), but the degree of bioaccumulation between each trophic level was less than 10x for each level above suspended particulates.

Two-hundred eighty-one selected samples of bird and fish livers, invertebrates and water from 1986-88 sampling were sent to the California Veterinary Diagnostic Laboratory System's Toxicology Laboratory at U.C. Davis for analysis of twenty trace and toxic elements. The results are most useful as baseline information, but enough comparative information exists for us to evaluate the toxicological significance of eight elements (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc). Some of the samples collected had elevated levels of arsenic, chromium, copper, mercury, nickel, and zinc which could be considered above background levels. Water samples from some of the evaporation pond complexes had arsenic levels approaching a range that may be of concern for sensitive species of aquatic life, and copper levels that might exceed the EPA criterion for the protection of freshwater aquatic life. All other samples with trace element concentrations above background levels did not represent conclusive evidence of detrimental impacts to aquatic life.

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INTRODUCTION

The Selenium Verification Study, begun in December 1985, is one element of the State Water Resources Control Board (State Board) study entitled "Selenium and Other Trace Elements in California". The purpose of the Verification Study is to measure selenium (Se) and trace elements in biota from suspected problem areas and determine if these potentially toxic elements occur at levels harmful to fish and wildlife.

The Selenium Verification Study is conducted by the California Department of Fish and Game under an interagency agreement with the State Board. Two units within the Department of Fish and Game (DFG) are involved in this study. Sample collection, data analysis, and data interpretation are performed by the Bay-Delta Project in Stockton. Sample preparation and analyses are performed by the analytical chemistry unit of the Fish and Wildlife Water Pollution Control Laboratory (WPCL) in Rancho Cordova.

The 1987-1988 Verification Study Program was developed based on results from October 1986 through May 1987 reported by White et al. (1988). The 1987-1988 Program emphasized investigations in the San Francisco Bay and Estuary, the Sacramento-San Joaquin Delta, the San Joaquin River and selected tributaries in the Grasslands area of western Merced County, and agricultural drainage water evaporation ponds in the southern San Joaquin Valley. Specific aspects of the study in San Francisco Bay-Estuary were designed to (1) measure site-specific rates of bioaccumulation in the food chain of diving ducks, (2) test for a difference in selenium levels between male and female ducks, (3) collect waterfowl in early winter in the San Francisco Bay area to determine selenium levels in their tissue upon arrival and in late winter to verify whether selenium is accumulated during the winter from sources in the Estuary, and (4) assess, for the second year, biological effects of tissue selenium concentrations measured in waterfowl through histological examination of liver, heart, and spleen. Catfish were collected from the San Joaquin River and tributary sites to evaluate the relative effect of upriver agricultural sources of selenium. Striped bass, an important sportfish and the focus of debate over Bay-Delta water quality/quantity issues, were collected again from the Sacramento and San Joaquin rivers. White sturgeon were collected from San Pablo Bay to compare with 1986-87 findings which showed an increase in selenium levels since 1986 and indicated potential public health impacts of selenium in sturgeon.

The presence of selenium in biota was determined by analyzing specific tissues. Selenium was measured in liver tissue of fish and birds to be consistent with previous studies and other on-going investigations of trace elements in biota and because it is a good indicator of an animal's exposure to selenium (Lemly 1982). Selenium was measured in the breast muscle of

bird species known to be consumed by humans and in the skeletal muscle of fish because of potential public health concerns. Selenium was measured in the soft tissue or, where they could not be dissected, in whole body composite samples of clams and mussels.

This report covers results from biota collected from September 1987 through May 1988. Findings are interpreted in relation to the continuously growing body of knowledge of selenium and its effects on biological systems. The tissue burden of selenium measured in an organism depends on its exposure history in terms of concentration and duration; species-specific rates of uptake and depuration; and the age, sex, and reproductive condition of individuals. Relating tissue burdens to local environmental conditions requires an understanding of factors affecting the speciation and bioavailability of selenium in natural systems; trophic pathways through which uptake of selenium occurs; processes of biological accumulation in individuals and biomagnification through food chains which produce high tissue concentrations of selenium from low ambient levels; and, particularly for migratory species, knowledge of selenium exposure at different locations in other seasons. Determining the implications of tissue burdens for the health of individual organisms and populations requires documenting adverse effects associated with above-normal tissue burdens; yet for most species normal levels are not well defined. Only a few studies have documented the toxic effects of selenium to fish and wildlife, most notably in wetlands contaminated with agricultural drain water (Ohlendorf et al. 1986 a, b; 1987) and in cooling water reservoirs receiving effluent from ash settling basins at coal-fired power plants (Lemly 1985). Selenium may impact individual organisms through impairment of various physiological functions and, even without mortality of individual adults, may eliminate populations by making individuals functionally sterile (Lemly 1987).

Protection of fish and wildlife from the toxic effects of selenium will involve establishing criteria for concentrations in water, a difficult task given the tendency for biological accumulation and magnification in food chains from low levels in water and the often small differences between essential levels and toxic levels of selenium in some animals. Recent laboratory experiments have provided some data on "effect levels" of selenium in fish and wildlife diets and tissues. However, only a few species have been included in experimental investigations. Other trace elements may react synergistically

FIELD AND LABORATORY [redacted]

TABLE 1. Common name, scientific name, family and species name code of birds, fishes and invertebrates collected in 1987-88.

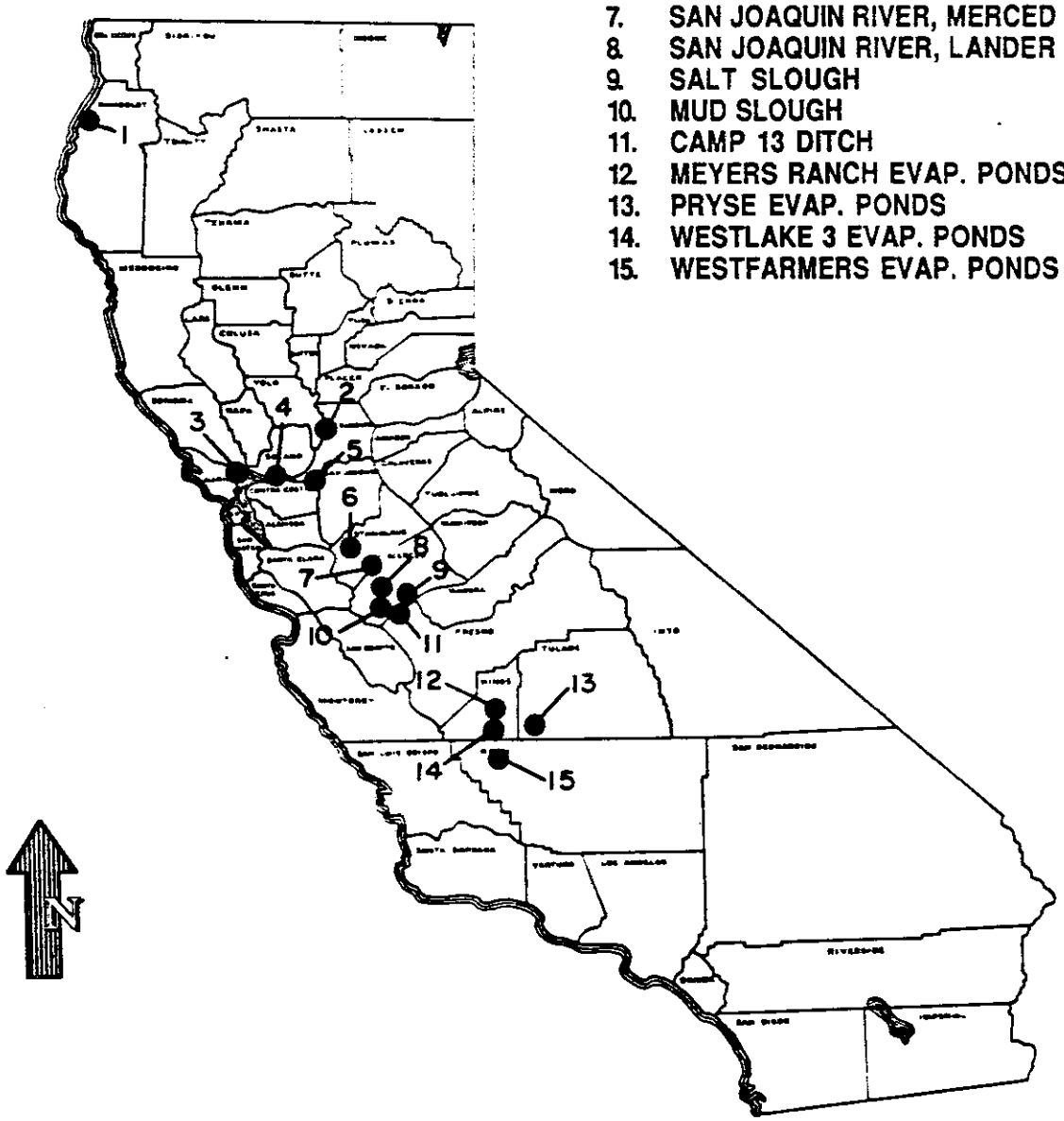
Common Name	Species	Family	Code
BIRDS			
lesser scaup	*Aythya affinis*	Anatidae	LSCAUP
greater scaup	*Aythya marila*	"	GSCAUP
surf scoter	*Melanitta perspicillata*	"	SCOTER
ruddy duck	*Oxyura jamaicensis*	"	RUDDYD
FISHES			
white sturgeon	*Acipenser transmontanus*	Acipenseridae	WSTRGN
white catfish	*Ictalurus catus*	Ictaluridae	WHTCAT
channel catfish	*Ictalurus punctatus*	"	CHNCAT
striped bass	*Morone saxatilis*	Percichthyidae	STBASS
brown bullhead	*Ictalurus nebulosus*	Ictaluridae	BRNBHD
green sunfish	*Lepomis cyanellus*	Centrarchidae	GRNSNF
INVERTEBRATES			
Asiatic freshwater clam	*Corbicula fluminea*	Corbiculidae	CRBCLA
Potamacorbula clams	*Potmacorbula spp*	Corbulidae	POTAMC
fingernail mussels	*Musculus senhousia*	Mytilidae	MUSSEN
bent-nosed clam	*Macoma nasuta*	Tellinidae	MACNAS
littleneck clam	*Protothaca staminga*	Veneridae	LTNECK
Japanese littleneck	*Tapes japonica*	Veneridae	TAPESJ
Baltic clam	*Macoma balthica*	Tellinidae	MACBAL
brine shrimp	*Artemia salina*	Artemiidae	BRNESH
water boatmen	undetermined		BOATMN

TABLE 2. Selenium Verification Collection Program, 1988.

	BIRDS	
LOCATION[1/]	SPP. COLLECTED[2/]	DATE COLLECTED
SUISB	SCOTER, LSCAUP, GSCAUP	10/87, 11/87, 02/88, 03/88
SNPBB	SCOTER, GSCAUP	11/87, 02/88

FIGURE - 1

1. HUMBOLDT BAY
2. SACRAMENTO RIVER, CLARKSBURG
3. SAN PABLO BAY
4. SUISUN BAY
5. ANTIOCH
6. SAN JOAQUIN RIVER, MAZE BLVD.
7. SAN JOAQUIN RIVER, MERCED RIVER
8. SAN JOAQUIN RIVER, LANDER AVENUE
9. SALT SLOUGH
10. MUD SLOUGH
11. CAMP 13 DITCH
12. MEYERS RANCH EVAP. PONDS
13. PRYSE EVAP. PONDS
14. WESTLAKE 3 EVAP. PONDS
15. WESTFARMERS EVAP. PONDS



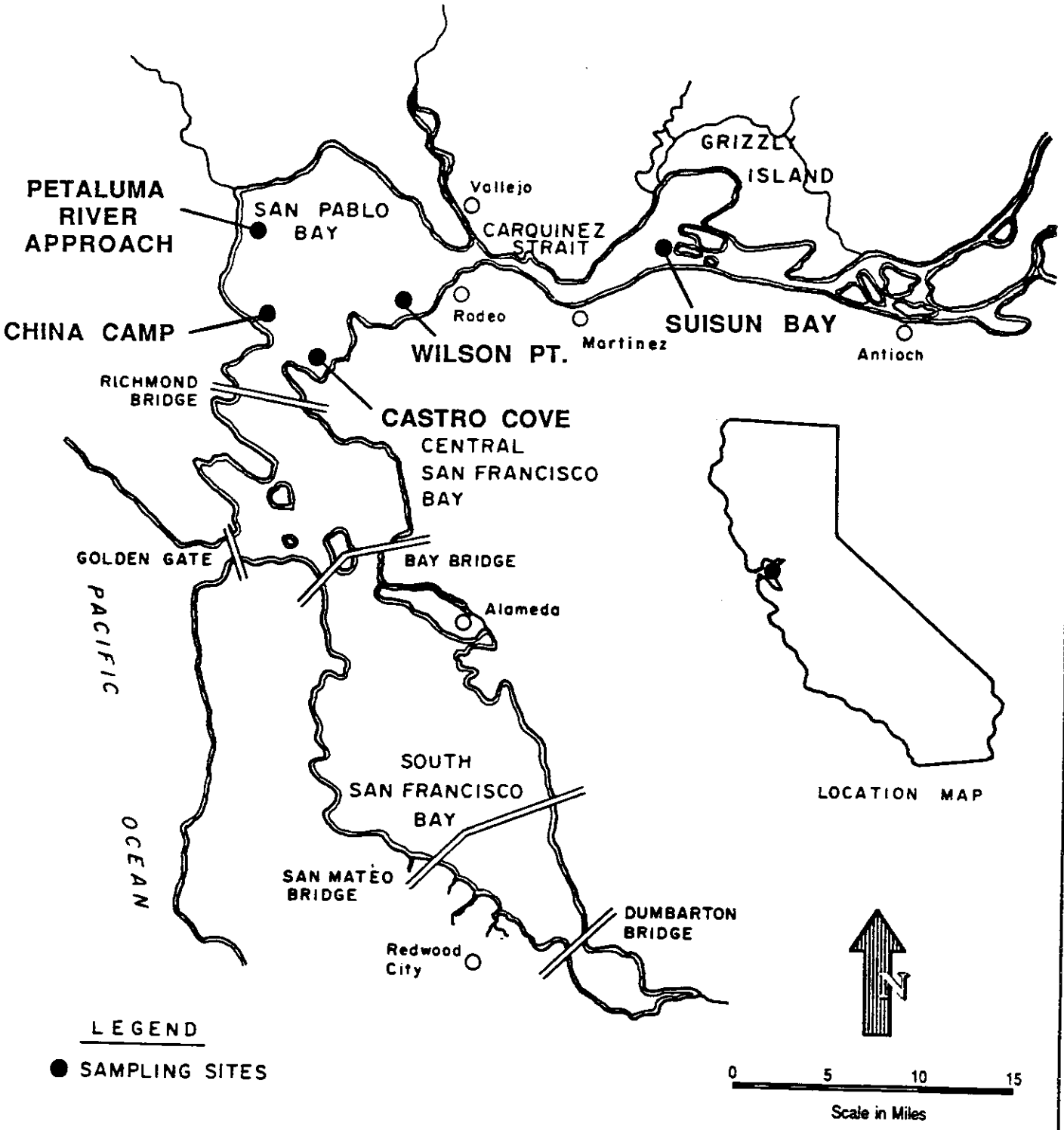
SELENIUM VERIFICATION STUDY: STATEWIDE DISTRIBUTION OF SAMPLING SITES - 1987-1988

TABLE 3. Selenium Verification Study Sampling Locations and Location Name Codes.

Location Code	Location[1/]
ANTCH	San Joaquin River near Antioch, Contra Costa County
CLKBG	Sacramento River near Clarksburg, Yolo County
CMP13	Camp 13 ditch, near Los Banos, Merced County
HMBLT	Humboldt Bay, Humboldt County
MEYER	Meyers Ranch evaporation ponds, near Stratford, Kings County
MUDSL	Mud Slough, at Kesterson NWR, Merced County
PRYSE	Calvin Pryse evaporation ponds, near Alpaugh Tulare County
SALTS	Salt Slough, near Stevinson, Merced County
SJRLN	San Joaquin River near Lander Avenue Bridge, Merced County
SJRMR	San Joaquin River downstream of Merced River confluence, Merced County
SNPBB	San Pablo Bay
SUISB	Suisun Bay, including Grizzly Bay
MAZEB	San Joaquin River at Maze Blvd. (Hwy 132) Stanislaus County
WFRMR	Westfarmer Evaporation Ponds, Twisselman Rd, Kern County
WLAKE	Westlake 3 Evaporation Ponds, Near Kettleman City, Kings Co

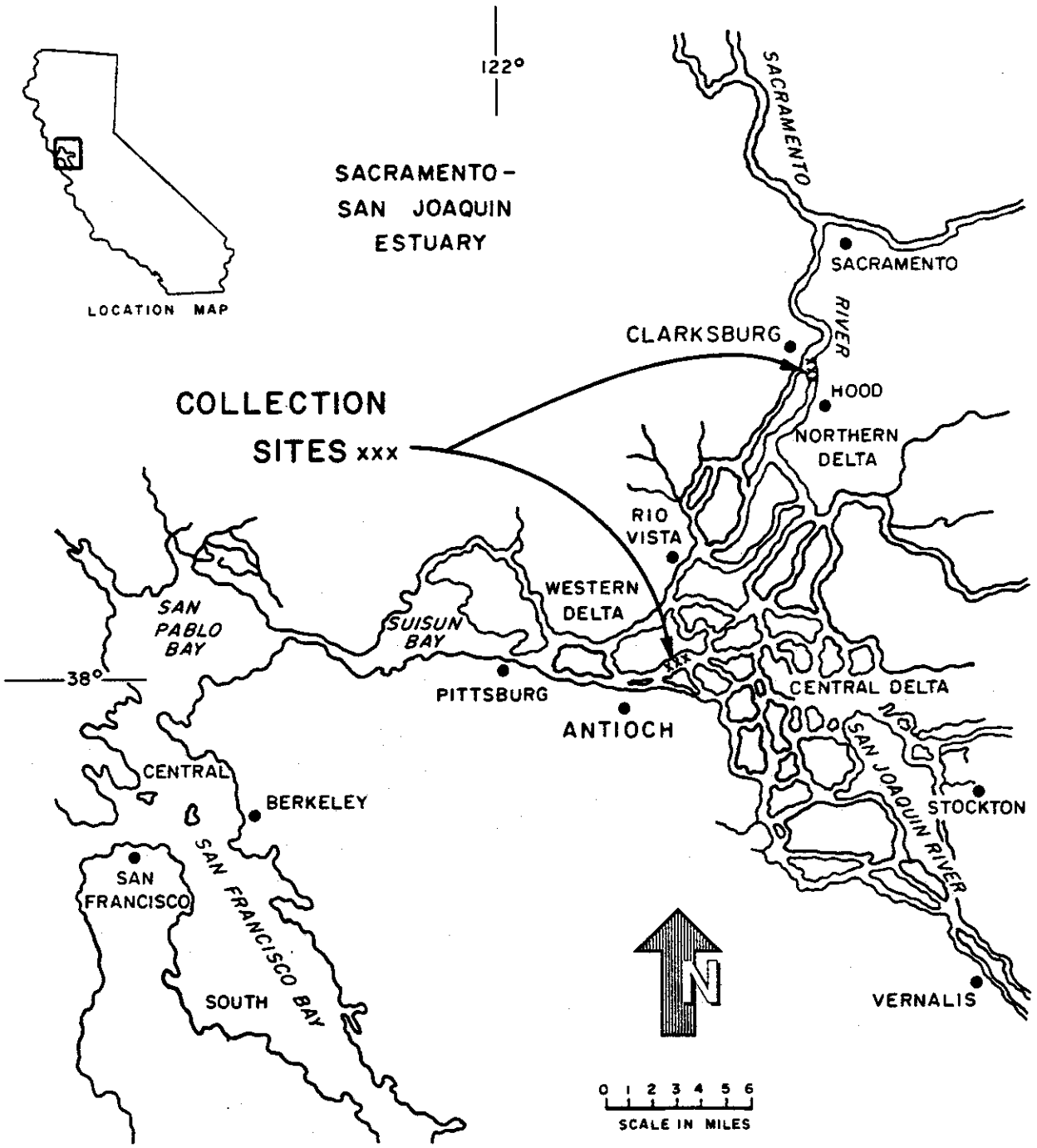
1/ See Appendix A for location description.

FIGURE - 2



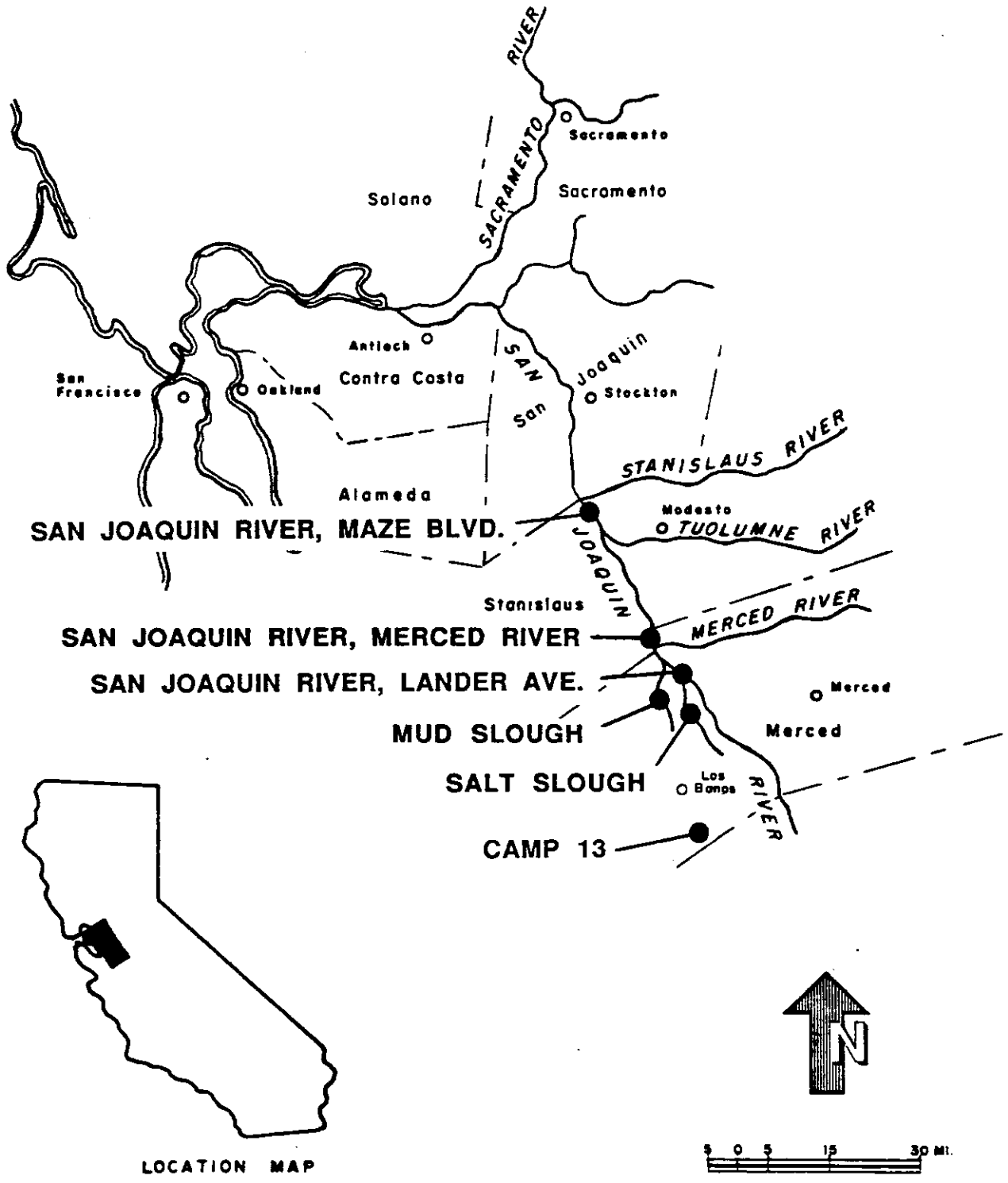
SELENIUM VERIFICATION STUDY: SAN FRANCISCO BAY-ESTUARY SAMPLING SITES - 1987-1988

FIGURE 3



SELENIUM VERIFICATION STUDY: STRIPED BASS COLLECTION SITES NEAR ANTIOCH ON THE SAN JOAQUIN RIVER AND NEAR CLARKSBURG ON THE SACRAMENTO RIVER

FIGURE 4



SELENIUM VERIFICATION STUDY: CATFISH SAMPLING SITES - 1987-1988

in ethyl alcohol for later identification. Food items were quantified by frequency of occurrence. Volumetric measurements were not made because digestion of soft parts had already occurred in many samples.

Spleen, liver and heart tissue samples were collected from a subsample of diving ducks and preserved in formalin. The tissue samples were later examined for histological abnormalities by the University of California, Davis.

Fish and Aquatic Invertebrate Collection and Processing

Fish sampling gear included hoop nets, gillnets, minnow seines, and hook and line. Sturgeon tissue samples were collected from sport-caught fish at the San Rafael harbor. Striped bass samples were from fish gillnetted or caught in fyke traps for the DFG's Striped Bass Health Monitoring Program. Clams were collected with a sled-mounted rake and a Petersen-type grab dredge. Evaporation pond invertebrates were collected with kick nets.

As soon as possible after collection, fish and invertebrate samples were placed in sealable plastic bags, frozen with dry ice and subsequently stored in a chest freezer at -12°C until delivered to WPCL for dissection, sample preparation, and analysis.

Tissues of each bird, striped bass, and white sturgeon were analyzed individually because data from individual organisms provide more information on variability within populations than that from several organisms in a composite sample. Nevertheless, catfish were analyzed in composite samples of six individuals to accommodate the constraint on total samples. Channel catfish and white catfish were not mixed in composite samples.

Water, Particulates, Plankton and Sediment Collection and Processing

To assess bioconcentration processes, samples of filtered water, non-filterable suspended particulates, plankton, and sediment were collected at each catfish sampling site, at the evaporation ponds and from Suisun, San Pablo and Humboldt bays. Collection times and frequencies coincided with the collections of birds or fish from each site. Bay samples were collected on consecutive high and low tides. Each type of sample was processed as follows.

Water samples were strained through a 75 um nylon plankton net before being filtered through a 0.45 um polycarbonate nuclepore filter in a Geotech 142 mm filter holder. The filtered water was acidified with nitric acid in inland samples and with hydrochloric acid in bay samples. Water samples were stored in 0.5 l or 1.0 l nalgene polyethylene bottles and were either frozen or refrigerated until analysis. Filtered water samples from the bays were analyzed for total selenium, selenite (Se IV), selenate (Se VI), and organic selenide and elemental

selenium (Se -II & 0) by Dr. G. A. Cutter, Old Dominion University, Norfolk, Virginia (following the methods of Cutter 1978, 1982, and 1983).

After the filtered water samples were collected, additional sample site water was pumped through the Nuclepore filter until clogging of the filter membrane began. The filter was then folded inward to retain the particulates, placed in a polyethylene vial, and frozen on dry ice for later determination of selenium in suspended particulates.

Plankton samples were collected with a #20 (75 um) nylon plankton net, and the contents then transferred to a polyethylene bottle and frozen until analysis at WPCL. These samples are composites of phytoplankton, zooplankton, and detritus greater than 75 um in size. Macroinvertebrates and larger pieces of detritus are removed, if necessary, before the samples are transferred to the sample bottles.

Sediment samples were initially collected with a shovel or Petersen-type grab sampler, and then subsampled with a clean plastic spoon to obtain a sample that had not been in contact with the sampling device. The dredged samples were put into polyethylene bottles and frozen immediately on dry ice. Samples were subsequently stored in a chest freezer at -12°C until delivered to WPCL.

LABORATORY OPERATIONS

Tissue Sample Preparation

All whole body samples and field dissected birds were received frozen at the Fish and Wildlife Water Pollution Control Laboratory (WPCL) in Rancho Cordova. Samples remained frozen at -15°C until dissected (within 3 months).

All samples were prepared for analysis in a "clean room" to minimize airborne contamination. All glassware, tools, and work surfaces were cleaned as described in Appendix B (Hammond 1986). Samples were dissected and homogenized as described in Appendix B.

After homogenization, the samples were refrozen until they were subsampled for analysis. Once the analysis was complete, a portion of each sample was transferred to a clean 30 mL linear polyethylene wide-mouth bottle (see Sample Container Preparation, Appendix B). These samples were then archived at -15°C.

WPCL Analytical Techniques and Quality Control for Selenium in Tissues

All tissue samples received by WPCL were analyzed for selenium by hydride generation atomic absorption spectrophotometry (HGAA). In addition to selenium, samples were also analyzed for moisture content. Analytical procedures used for tissue samples are described in detail in Appendix C (Hammond 1986).

Approximately 10 percent of the samples analyzed for selenium and moisture content were done in duplicate to determine intra-laboratory precision. The relative standard deviation (RSD = {standard deviation / mean} x 100), also called the coefficient of variation (Zar 1984), was calculated from the results of each duplicate pair and is listed in Appendix D. The results of duplicate sample analyses for selenium averaged 2.2 percent RSD (range 0 to 10), while results of duplicate moisture determinations averaged 0.26 percent RSD (range 0 to 4.1). Based on duplicate analyses we conclude that the selenium and moisture determinations demonstrate acceptable levels of precision.

National Bureau of Standards (NBS) reference materials were analyzed with each set of samples to verify accuracy (Table 4). Results of selenium analyses of NBS reference materials indicated accuracy within the 95 percent statistical tolerance limits of the certified selenium concentration in bovine liver (NBS 1577a), and the noncertified value of tuna (NBS 50). WPCL results of analyses of bovine liver demonstrated a small negative bias for selenium, while results of analyses of the tuna (NBS 50) exhibited a small positive bias. The average results reported by WPCL for the analysis of selenium in mussel

Table 4. WPCL total selenium analysis of tissue reference materials reported in ug/g (ppm), dry weight in freeze dried samples.

Certified Se Value	NBS 50[1/2/] (Tuna) 3.6±.4		NBS 1577a (Bovine Liver) 0.71±0.07		NIES #6[2/3/] (Mussel) 1.5
HGAA Results	3.9	3.8	0.68	0.67	1.6
	3.8	3.8	0.68	0.72	1.5
	3.8	3.9	0.71	0.69	1.4
	3.9	3.7	0.70	0.67	1.5
	3.7	3.8	0.65	0.68	1.4
	4.0	4.0	0.71	0.72	1.4
	3.9	3.8	0.67	0.68	
	3.8		0.67	0.66	
			0.75	0.70	
				0.69	
Mean	3.8		0.69		1.5
Std. Error [4/]	0.02		0.006		0.03
RSD (%)[5/]	2.4		3.6		5.6
Bias (%)[6/]	5.6		-2.8		0

1/ National Bureau of Standards, Washington, D.C. 20234

2/ Non-certified, but accepted value of constituent element.

3/ National Institute of Environmental Studies, Japan Environmental Agency.

4/ Standard error = standard deviation/(number of values).

5/ Relative standard deviation = (standard deviation/mean) X 100.

6/ Bias (% difference) = (experimental value - reference value)/reference value X 100.

tissue (NIES 6) is identical to the value reported by the National Institute for Environmental Studies, Japan. Results in Table 4 indicate that HGAA provides acceptable accuracy for the analysis of selenium in tissue.

VDTL Analytical Techniques and Quality Control for Trace Elements in Tissue

Approximately 250 homogenized tissue samples were sent to the Veterinary Diagnostic Laboratory System's Toxicology Laboratory (VDTL). In addition to selenium and moisture analyses, the samples were also analyzed for nineteen other trace elements (raw data reported in Ardans et al. 1988). A portion of the sample was acid digested and diluted prior to an Inductively Coupled Argon Plasma Spectroscopy (ICP) multi-element screen for aluminum, barium, beryllium, boron, cadmium, copper, iron, lithium, magnesium, manganese, molybdenum, nickel, selenium, vanadium, and zinc. An aliquot of this solution was subsampled prior to the ICP analysis and used for the analysis of cadmium, chromium, lead, and silver by Graphite Furnace Atomic Absorption (GFAA) with Zeeman background correction. In addition, one gram of each sample was lyophilized for moisture determination. All methods of analyses and results are reported in Ardans et al. (1988).

A nine element round-robin was completed by WPCL, The University of Missouri, and VDTL as part of VDTL quality control for the analysis of trace elements (Appendix E). The nine elements include: arsenic, cadmium, chromium, copper, lead, mercury, selenium, silver, and zinc. At WPCL arsenic and selenium were analyzed as described in Appendix C. Mercury analyses were completed by a potassium permanganate-acid digestion followed with cold vapor atomic absorption spectrophotometry (Hatch and Ott 1967) which is described in detail in Appendix C. The other elements were digested with nitric acid (Adrian 1971). At WPCL, chromium and lead were analyzed using GFAA with Zeeman correction. Silver and cadmium samples were analyzed with deuterium correction. Sample digestion and instruments utilized at WPCL for the trace element round-robin are described in Appendix C.

Methods used at VDTL, results, and statistical comparison of the round-robin results are reported in (Ardans et al. 1988). VDTL concluded in this report that the two sets of data from the round-robin were in excellent agreement and had produced a highly correlated data set.

Additional elements were analyzed by neutron activation analysis (NAA) at the University of Missouri following the method of McKown and Morris (1978), and are presented in Appendix F. These additional elements are from the same samples that were analyzed in the nine element round-robin, and are for information only.

Interlaboratory Comparison Of Selenium In Tissue

Appendix G contains a comparison of approximately 250 selenium values and %RSD for samples analyzed by VDTL and WPCL.

The average %RSD for bird livers is 5.4; for fish livers 5.3; and for invertebrates 15. The correlations between VDTL and WPCL data are r=0.997 for bird liver data; r=0.980 for fish livers; and r=0.994 for invertebrates. These results demonstrate excellent agreement between analyses performed by the two laboratories indicating that WPCL's results are repeatable and suggesting that WPCL's selenium analyses are reliable.

Analytical Techniques and Quality Control for Selenium in Water

Water samples were collected in polyethylene bottles which had been previously cleaned with 1.0 M nitric acid (analytical reagent grade) and rinsed with Type I water. The unfiltered water samples were preserved at the time of collection with hydrochloric acid to a final concentration of 0.08 Molar. The samples were frozen and remained frozen until the time of analysis.

A total of fifty water samples were analyzed for selenium at WPCL. All of the WPCL results are reported in Appendix H. Thirty-three of these water samples were sent in the original containers to VDTL and reanalyzed. Also, four water samples were sent to the Department of Water Resources (DWR) for selenium analysis. The VDTL, DWR, and WPCL water sample results are shown in Table 5. The selenium results show good agreement for the quality control samples even though the laboratories used different sample digestion procedures. The average %RSD between WPCL and VDTL values is 5.6% and the two sets of data have a correlation coefficient of r=0.86. The average %RSD between the four WPCL and DWR values is 1.3% and they have an r=0.999.

DWR analyzed water samples for selenium using an acid digestion method (Presser and Barnes 1984) followed by HGAA using the method of additions. WPCL used a magnesium nitrate dry ash digestion followed by HGAA (Appendix C) for selenium determination in water. This dry ash technique had a low detection limit (1.0 ug/kg) with little background interference, and produced consistent results. The VDTL analytical procedures for selenium in water are described in their report (Ardans et al. 1988).

In Table 6, results from WPCL analysis of NBS and USGS reference water samples are listed. The results from the round-robin samples sponsored by the San Joaquin Valley Drainage Program are listed in Table 7. In both Tables 6 and 7, all WPCL results for selenium are in good agreement with the accepted reference water values.

The VDTL also analyzed three blind USGS reference water samples for selenium (Appendix I). The VDTL analytical procedures for selenium in water are described in their report (Ardans et al. 1988).

Water samples were sent to Old Dominion University, Norfolk, Virginia, for speciation of selenium. The method used for

Table 5. Comparison of selenium water results VDTL, WPCL, and DWR in ug/L (ppb). [I.S. = insufficient sample]

Sample Number	Collection Site	VDTL	WPCL	% RSD VDTL vs WPCL	DWR	% RSD WPCL vs DWR
L2033	CMP13	71.8	70.	1.8	-	-
L2034	SJRLN	4.9	5.0	1.4	-	-
L2035	MUDSL	5.4	5.3	1.3	-	-
L2036	SALTS	21.2	19.	7.7	-	-
L2037	SJRMR	6.2	6.1	1.2	-	-
L2038	MAZEB	2.6	2.5	2.8	-	-
L2039	HMBLT	<1.0	<1.0	0	-	-
L2040	HMBLT	<1.0	<1.0	0	-	-
L2041	WFRMR	163.	160.	1.3	-	-
L2042	WFRMR	167.	460.	66.1	-	-
L2043	WFRMR	111.	100.	7.4	-	-
L2044	WLAKE	I.S.	2.9	-	3.	2.4
L2045	PRYSE	9.9	7.9	15.9	-	-
L2046	MEYER	<1.0	<1.0	0	-	-
L2047	MEYER	<1.0	<.10	0	-	-
L2048	WLAKE	2.9	2.7	2.6	-	-
L2049	WLAKE	6.	4.4	21.8	-	-
L2050	SUISB	I.S.	<1.0	-	1.	0
L2051	SUISB	<1.0	<1.0	0	-	-
L2052	SNPBB	I.S.	<1.0	-	<1.	0
L2053	SNPBB	<1.0	<1.0	0	-	-
L2054	SNPBB	<1.0	<1.0	0	-	-
L2055	SNPBB	<1.0	<1.0	0	-	-
L2056	SNPBB	<1.0	<1.0	0	-	-
L2057	SNPBB	<1.0	<1.0	0	-	-
L2058	SNPBB	<1.0	<1.0	0	-	-
L2059	SNPBB	<1.0	<1.0	0	-	-
L2060	MUDSL	21.3	20.	4.5	-	-
L2061	SJRLN	I.S.	<1.0	-	-	-
L2062	CMP13	67.	62.	5.5	-	-
L2063	SJRMR	10.1	10.	0.7	-	-
L2064	SALTS	16.4	16.	1.7	-	-
L2065	MAZEB	I.S.	5.2	-	5.	2.8

Table 6. Results of WPCL selenium analysis in National Bureau of

Table 7. Results of selenium analyses of reference material from the San Joaquin Valley Drainage Program Round-Robin.

Sample Type	Origin[1/]	Accepted[2/] Selenium Values	WPCL Selenium Values	No. of Analyses	S.D.
Water (ug/L):					
NBS 1643b	NBS	9.87 (0.51)	10.2	3	0.23
QAWS-7 + 60 ppb	USGS-UCD	112.5 (2.5)	114.	2	0.70
QAWS - 7 + 30 ppb	USGS-UCD	82.5 (2.5)	83.5	3	0.43
QAWS - 7 + 0 ppb	USGS-UCD	52.5 (2.5)	55.1	3	0.32
Sediment (ug/g):					
KS-1-5	USBS	63.0 (5.9)	65.	3	1.7

1/ United States Geological Survey-University of California Davis (USGS-UCD) are reference samples spiked with a known amount of selenium by UCD; United States Bureau of Standards (USBS); National Bureau of Standards (NBS).

2/ Values in parenthesis are standard deviations. Only the NBS water sample has a certified Se value. The USGS samples are considered to be internal reference values only.

speciation is described in general in Cutter, 1987, and laboratory methods are described in detail in Cutter, 1978, 1982, and 1983.

Analytical Techniques for Trace Elements in Water

A total of 33 water samples from the 1987-1988 Selenium Verification Study and three blind water reference samples were analyzed by VDTL for the following elements: aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, selenium, silver, vanadium and zinc. Analytical methods and results are reported in the VDTL report (Ardans et al. 1988). The VDTL results of three USGS reference water samples are reported with the accepted values in Appendix I.

Analytical Techniques for Selenium in Sediment, Filter Residue and Plankton

All sediment, filter residue, and plankton samples were collected in clean plastic bottles and frozen at the time of collection. The samples remained frozen until analyzed.

A method of analysis for selenium in sediment was developed at WPCL (based on May 1982) because no standard method was available, and was used for all sediment samples as described in Appendix C. Just recently, EPA approved methods have been developed to analyze for selenium in sediment but WPCL

STATISTICAL METHODS

Selenium concentrations were transformed to common logarithms (log_{10}) prior to statistical analysis because distributions were non-normal and variances tended to be proportional to sample means (coefficients of variation relatively similar). Two-way analysis of variance was used to test the effects of time period and collection location on selenium concentrations. Because sample sizes varied, a regression approach was used to partition sums of squares in testing hypotheses. This approach tested the significance of individual model components after adjusting for all other effects in the ANOVA model. When a main effect was significant, Tukey's studentized range test (HSD) was used to compare main-effect means and identify nonsignificant subsets. One-way ANOVA was used to test the effect of time period or location when data were not available for all time period-location combinations. (Simple correlation was used to test for a relationship between size and selenium concentration.) These analyses were performed on a micro-computer with SAS statistical package (SAS Institute Inc. 1985).

Geometric means represent the values used to test for significant differences between groups and, therefore, are presented in the text and in tables illustrating the results of statistical analyses. Arithmetic means of untransformed data are plotted in figures used to illustrate the range and variability of the raw data. Differences between geometric and arithmetic means were usually small.

Statistical significance was determined at P=0.05; references in the text to "significant" differences unaccompanied by a probability value imply statistical significance at the 0.05 probability level or higher.

RESULTS AND DISCUSSION

SELENIUM IN WINTERING DIVING DUCKS

Since 1986, the Verification Study has measured selenium (Se) in the tissues of several species of diving ducks that use San Francisco Bay and other California coastal bays during the winter (White et. al. 1987, 1988). Initial findings established that surf scoters and scaup found on San Francisco area bays contained higher Se concentrations than the background levels measured in the same species wintering at Humboldt Bay on the northern California coast. Follow-up investigations during the 1986-1987 winter confirmed these results for surf scoters and scaup; added another species of diving duck, the canvasback; and a second control site, Morro Bay. Results from 1986-1987 indicated the Se concentration in diving ducks increased during the winter. Although Bay water contained less than one microgram of dissolved Se per liter (parts per billion, ppb), Se was concentrated by organisms and biomagnified through successive levels in the food chain, accumulating to relatively high concentrations (tens of parts per million) in bird tissues. Experiments with transplanted mussels and oysters indicated Se enrichment in areas near some oil refinery discharges in Suisun and San Pablo bays. Limited histological examination of diving duck tissues produced no evidence of selenium-induced pathology associated with elevated tissue concentrations.

Verification Study efforts in 1987-1988 were directed toward reaffirming the winter period increase in Se levels in diving ducks, evaluating possible trends over time, clarifying a confusing picture with respect to differences in exposure of waterfowl to Se contamination among local bays, testing for a difference in Se levels between male and female ducks, learning more about the food chain biomagnification of Se, and further assessing possible biological effects of Se in diving ducks. Effort focused on Suisun and San Pablo bays with Humboldt Bay for comparison. Emphasis was placed on surf scoters because the existing scoter data base covers more years than those for other species, scoter food habits are relatively consistent throughout their winter range, and scoters are more vulnerable than other diving ducks, so we are more successful in completing scheduled collections. Some scaup were included in our sampling despite the confounding effect of both greater scaup and lesser scaup using various wintering grounds within the study area. Canvasback were excluded to avoid duplication of investigations of the species on San Francisco Bay planned by the U. S. Fish and Wildlife Service (H. Ohlendorf Pers. Comm.).

Surf Scoters

Selenium concentrations increased in surf scoters during the 1987-1988 wintering period on Suisun and San Pablo Bays (Figure 5, Table 8). The average Se concentration in muscle of male

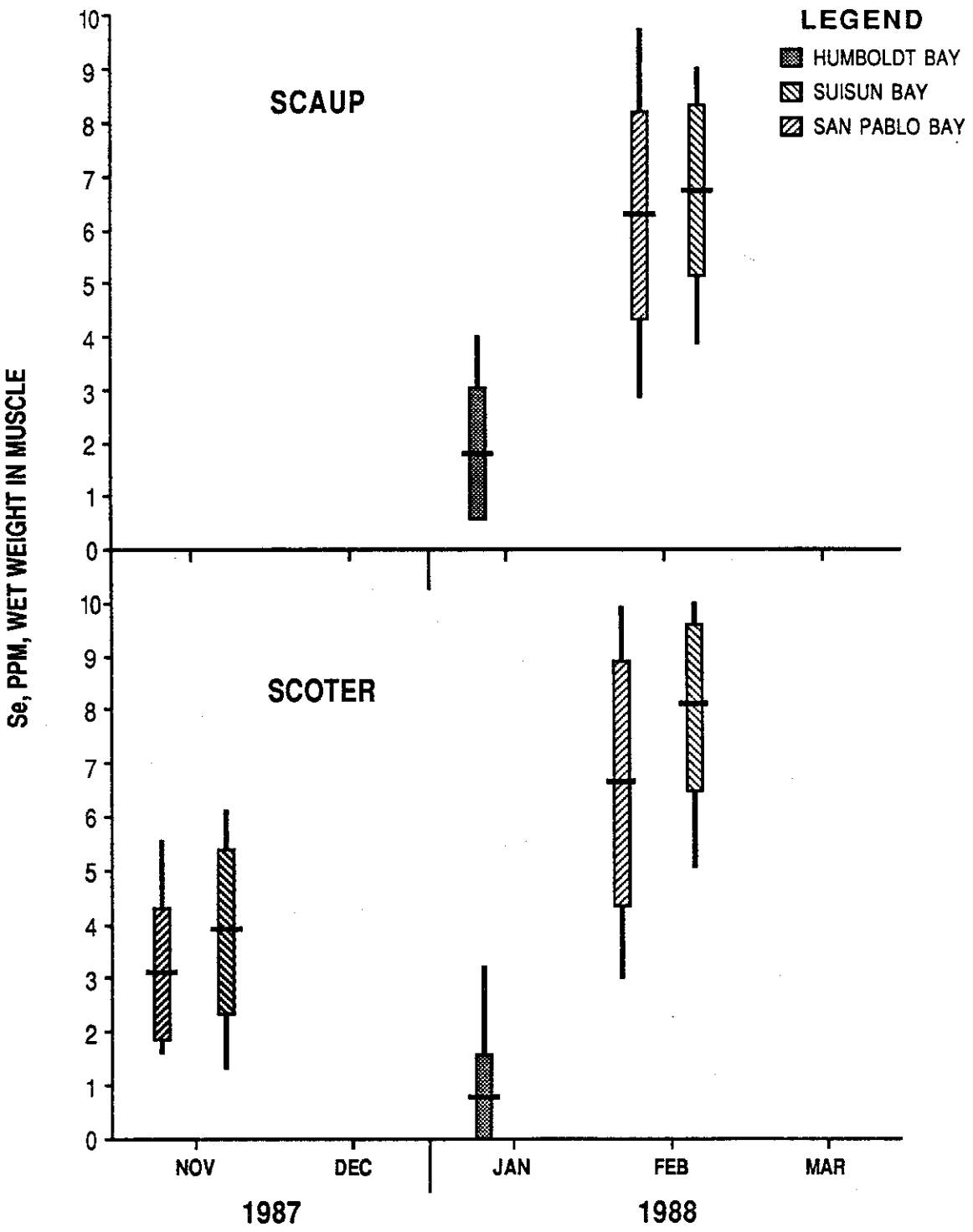


FIGURE 5. Selenium concentrations (arithmetic $\bar{x} \pm$ s. d., & range; ppm, wet weight) in muscle tissue of diving ducks, 1987 - 1988.

Table 8. Geometric mean selenium concentrations (ug/g, wet wt. (ppm)) and range of concentrations in muscle and liver of diving ducks collected between fall 1987 and late-winter 1988.

Species	Date	Location (Bay)	Muscle N	Muscle $\bar{x}$	Muscle Range	Liver N	Liver $\bar{x}$	Liver Range
Surf Scoter	11/87	Suisun	10	3.6	1.3-6.1	10	27	18-45
	11/87	San Pablo	10	2.9	1.6-5.5	10	25	17-50
	1/88	Humboldt	10	0.60	0.34-3.2	10	2.5	1.2-16
	2/88	Suisun	10	8.9	7.8-10	10	58	45-84
	2/88	Suisun	10	6.9	4.9-10	10	53	41-71
	2/88	San Pablo	10	6.2	3.0-9.9	10	36	16-51
Scaup	1/88	Humboldt[1/]	10	1.5	0.68-4.0	10	3.4	2.1-7.2
	2/88	Suisun[2/]	10	6.6	3.9-9.0	10	23	9.2-31
	2/88	San Pablo[3/]	10	6.0	2.9-9.7	10	12	7.2-26

1/ Greater Scaup (9) Lesser Scaup (1)
2/ Lesser Scaup (10)
3/ Greater Scaup (10)

surf scoters from Suisun Bay was 2.5 times higher in February ($\bar{x}$=8.9 ppm) than at the beginning of the winter ($\bar{x}$=3.6 ppm in November 1987). In San Pablo Bay, the average selenium concentration in scoter muscle more than doubled from 2.9 ppm in November 1987 to 6.2 ppm in February 1988. Selenium concentration in scoter liver also increased significantly during the winter (Figure 6, Table 8) in ducks from both bays, reaching average levels of 58 ppm and 36 ppm in Suisun Bay and San Pablo Bay, respectively. These results strongly support the conclusion of White et. al. (1988) that diving ducks accumulate Se while wintering on San Francisco area bays. Data from 1986-1987 indicated Se concentration increased during the winter in scoter and scaup muscle but not in liver. White et al. (1988) hypothesized that rapid Se uptake by liver in the time between arrival and collection of ducks on San Francisco Bay obscured the overall seasonal increase in liver Se levels during the 1986-1987 winter. Better monitoring of migrations and increased collecting efficiency in early winter 1987 allowed birds to be collected sooner after arrival, making Se levels in tissue samples more likely to be representative of pre-winter levels, particularly in liver. Consequently, significant increases in Se concentration between early and late winter were measured in liver as well as muscle from scoters.

Analysis of variance indicated that the bay from which a scoter was collected had a significant effect on its Se content, i.e. scoters from Suisun Bay contained higher Se concentrations than those from San Pablo Bay (Table 8). The difference was found in muscle and liver and was consistent between seasons. The concentration of Se in food organisms consumed by scoters in the respective bays may explain the bird tissue Se levels (Table 9).

The most important food item for scoters in Suisun Bay (Appendix J) was a small, recently introduced clam of the genus Potamocorbula which contained approximately 0.5 ppm Se (wet wt.) in samples of whole clams including shells (Table 9). Scoters consumed other food items in Suisun Bay, however, no other food item occurred in more than 20% of scoters examined (Table 10). Potamocorbula also was an important food for scoters in San Pablo Bay (Table 10), where samples contained 0.53 ppm Se (wet wt.) (Table 9). Two other bivalves also were important diet items for scoters in San Pablo Bay (Table 10), a mussel (Musculus senhousia) with 0.18 ppm to 0.43 ppm Se (wet wt.) in several samples and the Japanese littleneck clam (Tapes japonica) with approximately 0.30 ppm Se (Table 9). Greater utilization of food organisms with lower Se content by San Pablo Bay scoters compared to those in Suisun Bay may account for lower Se levels in tissue of scoters from San Pablo Bay.

Significant accumulation of Se by wintering scoters was found in both San Pablo Bay and Suisun Bay in 1987-88, as was the [illegible] 1986-1987. However, during 1986-1987

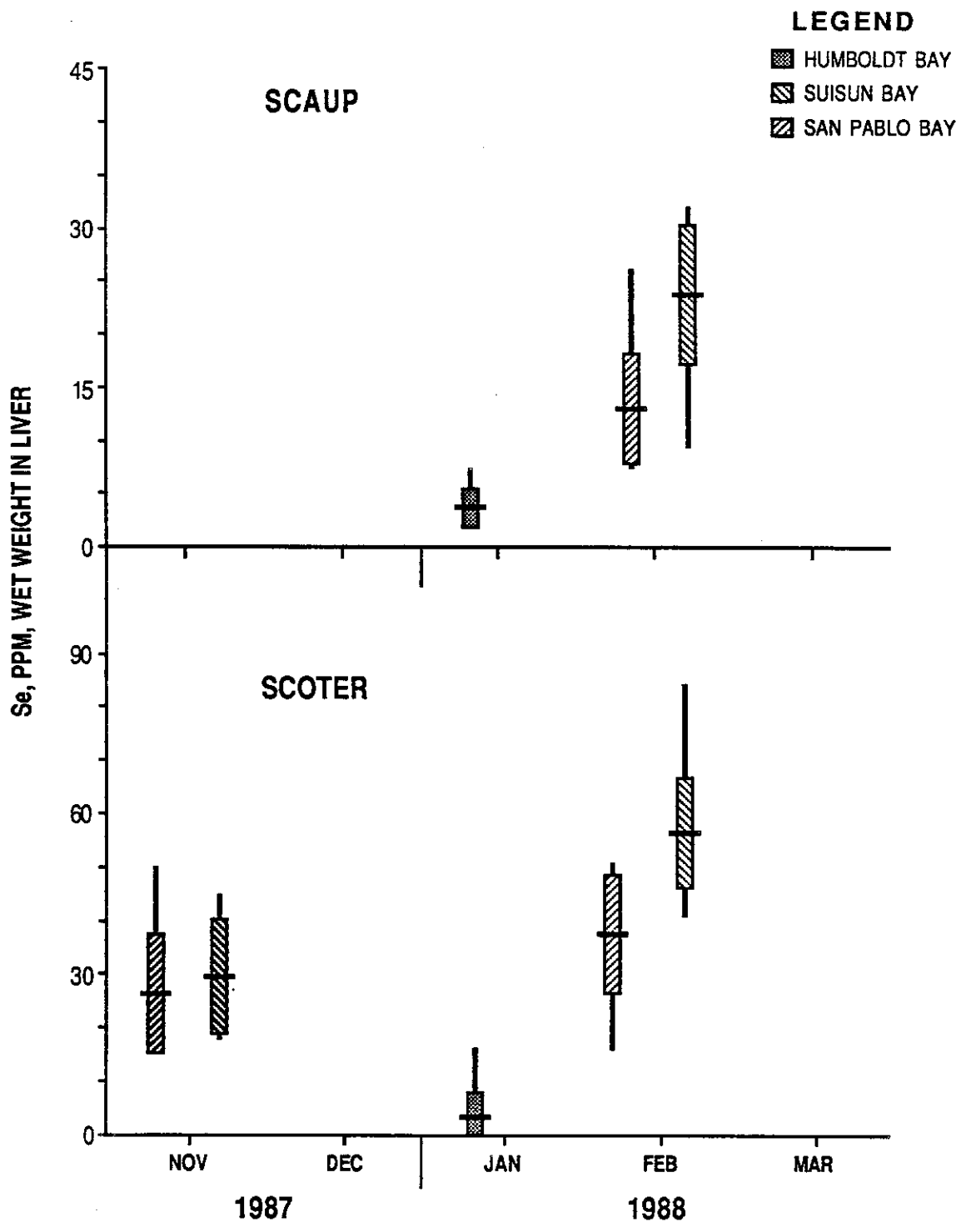


FIGURE 6. Selenium concentrations (arithmetic $\bar{x} \pm$ s. d., & range; ppm, wet weight) in liver tissue of diving ducks, 1987 - 1988.

Table 9. Selenium concentrations in clams and mussels from Suisun, San Pablo, and Humboldt bays. Results are in ug/g (ppm), dry weight with wet weight values in parenthesis. Each value is for one composite sample.

Location	Subsite	Species	Oct 1987	Nov 1987	Dec 1987	Jan 1988	Feb 1988
Suisun Bay							
	Roe Island	Corbicula fluminea[1/]	7.3 (0.87)		5.7 (0.80)		5.8 (0.81)
			5.5 (0.83)		5.5 (0.82)		5.7 (0.80)
							5.7 (0.74)
		Potamocorbula[2/]	1.0 (0.48)		0.91 (0.43)		1.4 (0.46)
					0.90 (0.45)		0.96 (0.52)
							1.1 (0.51)
San Pablo Bay							
	Wilson Pt.	Musculus senhousia[2/]		0.50 (0.16)			
	"			0.82 (0.18)			
	"			0.63 (0.19)			
	Castro Cove			1.5 (0.40)			
	"			1.3 (0.46)			
	China Camp			3.8 (0.30)			
	"			1.9 (0.40)			
	"			1.1 (0.43)			
	Petaluma R.	Potamocorbula[2/]		1.0 (0.47)			1.3 (0.67)
	"			1.4 (0.59)			
	Castro Cove	Tapes japonica[2/]		0.54 (0.29)			0.52 (0.31)
Humboldt Bay							
		Macoma nasuta[1/]				1.9 (0.27)	
						1.7 (0.26)	
		Macoma balthica[1/]				2.1 (0.29)	
		Protothaca staminea[1/]				2.3 (0.37)	

1/ Dissected flesh sample only, not including shell.
2/ Whole animal sample, including shell, as were too small or thin shelled to dissect.

Table 10. Food items found in at least 20% of surf scoters and scaup at each collection site.

FOOD ITEMS	Species and Location[1/] Scaup SUISB	Scaup SNPBB	Scaup HMBLT	Surf Scoter SUISB	Surf Scoter SNPBB	Surf Scoter HMBLT
Mollusca						
Gastropoda						
Margarites salmoneus			X			
Alvinia spp.			X			
Mitrella spp.			X			
Odostomia spp.			X			
Unidentified Gastropods			X			
Bivalvia						
Musculus senhousia		X			X	
Transenella spp.			X			
Corbicula fluminea	X					
Tapes japonica		X			X	
Solen sicarius						X
Potamocorbula spp.	X	X		X	X	
Unidentified bivalves			X			
Miscellaneous						
Herring (*Clupea harengus*) eggs		X				

1/ SUISB - Suisun Bay
SNPBB - San Pablo Bay
HMBLT - Humboldt Bay

average level lower than in early winter samples (White et al. 1988). Selenium in Corbicula, the major food item for Suisun Bay diving ducks in 1986-1987 did not decline, hence dietary uptake was presumed constant. There was no other evidence to explain a late winter reduction in Se levels in diving ducks continuously using Suisun Bay through the winter. Based on bird counts provided by the Fish and Wildlife Service indicating a redistribution of wintering diving ducks during this period, White et al. (1988) suggested the decline was due to the immigration of birds with low Se levels to Suisun Bay from other wintering areas south of San Francisco Bay and the inclusion of transient birds in late winter Suisun Bay bird collections. Findings for 1987-1988 support the conclusion that diving ducks continue to accumulate Se through their winter stay on San Francisco area bays.

Scoters were obtained from Humboldt Bay in January 1988 to compare with birds from Suisun and San Pablo bays. A single collection period was deemed adequate to verify Se levels in diving ducks since previous work had revealed only minor seasonal increases in diving duck tissue Se content at Humboldt Bay (White et al. 1987, 1988). The middle of the wintering period was chosen for collections to insure prolonged exposure of wintering scoters to the Humboldt Bay environment and to minimize the probability of including northward migrants returning from wintering areas to the south. Surf scoters from Humboldt Bay averaged 0.60 ppm Se in muscle and 2.5 ppm in liver (Table 8). These levels are significantly lower than than those in scoters from Suisun and San Pablo bays (Figures 5 and 6) which, in early winter, averaged 5 to 6 times higher than Humboldt Bay in muscle and 10 to 11 times higher in liver and, by late winter, were 10 to 14 times higher than Humboldt Bay in muscle and 14 to 22 times higher in liver. In a direct comparison among these three locations, Se concentration in scoters from Suisun Bay did not differ from those in San Pablo Bay as a two area comparison had indicated. Differences between San Pablo and Suisun Bay scoter Se levels are small compared to the amount by which those levels exceed Se concentrations in scoters at Humboldt Bay. Since the a-posteriori test used for the three areas is conservative to compensate for over-testing the data it judged these small differences to be insignificant. The average Se concentration in both muscle and liver of scoters from Humboldt Bay in 1988 was the lowest among the three years we have sampled there. The highest average concentrations were measured in 1987 ($\bar{x}$=0.97 ppm in muscle, $\bar{x}$=4.2 ppm in liver). Overall, however, there was no statistically significant difference among the three years. Between-year variation probably reflects slight differences in the time of sampling, natural variability in Se levels in scoters and the possible inclusion of late-season migrants.

Our data show selenium concentrations in scoters using San Francisco area bays increased significantly during winter 1987-1988 and were significantly higher than background levels in scoters at Humboldt Bay. To determine if there is an increasing trend in Se in scoters, 1988 late-winter Se levels

were compared with Se concentrations in scoters collected in late winter 1986 and 1987. Diving ducks were collected during late winter in all three years only from San Pablo, Suisun, and Humboldt Bays. Scoters included in this analysis were obtained from San Pablo Bay in March 1986, March 1987, and February 1988; from Suisun Bay in January 1986, January 1987,and February 1988; and from Humboldt Bay in February 1986, March 1987, and January 1988.

In both San Pablo and Suisun bays, Se levels in scoters were significantly higher in 1988 than in 1986, by about 3-4 times in muscle tissue and by about 2.5 times in liver (Table 11, Figures 7 and 8). Scoters from San Pablo Bay also contained significantly more selenium in 1987 than in 1986 but 1987 levels were not different from 1988; those from Suisun Bay in 1987 were similar to 1986 and significantly less than 1988. Patterns of variation and the statistical significance of differences were identical for both muscle and liver Se concentrations. Although data from only three years are not a [illegible] for a strong conclusion about trends, these

Table 11. Comparison of selenium concentrations (ug/g, wet wt. (ppm)) in diving ducks collected during selected early and late winter periods of 1986 to 1988 from San Pablo Bay, Suisun Bay, and Humboldt Bay. Geometric means in each row followed by the same letter are not significantly different ($p<0.05$).

	1986	1987	1988
Surf Scoter		Early Winter	
Muscle			
San Pablo Bay	-	2.3 a	2.9 a
Suisun Bay	-	2.9 a	3.6 a
Liver			
San Pablo Bay	-	26 a	24 a
Suisun Bay	-	22 a	27 a
		Late Winter	
Muscle			
San Pablo Bay	1.6 a	5.7 b	6.2 b
Suisun Bay	3.1 a	3.7 a	8.9 b
Humboldt Bay	0.78 a	0.97 a	0.60 a
Liver			
San Pablo Bay	15 a	38 b	36 b
Suisun Bay	21 a	24 a	58 b
Humboldt Bay	3.1 a	4.2 a	2.5 a
		Late Winter	
Scaup			
Muscle			
San Pablo Bay	1.4 a	3.7 b	6.0 c
Suisun Bay	2.1 a	2.4 a	6.6 b
Humboldt Bay	1.1 a	2.1 a	1.5 a
Liver			
San Pablo Bay	4.9 a	8.9 b	12 b
Humboldt Bay	2.7 a	4.1 a	3.4 a

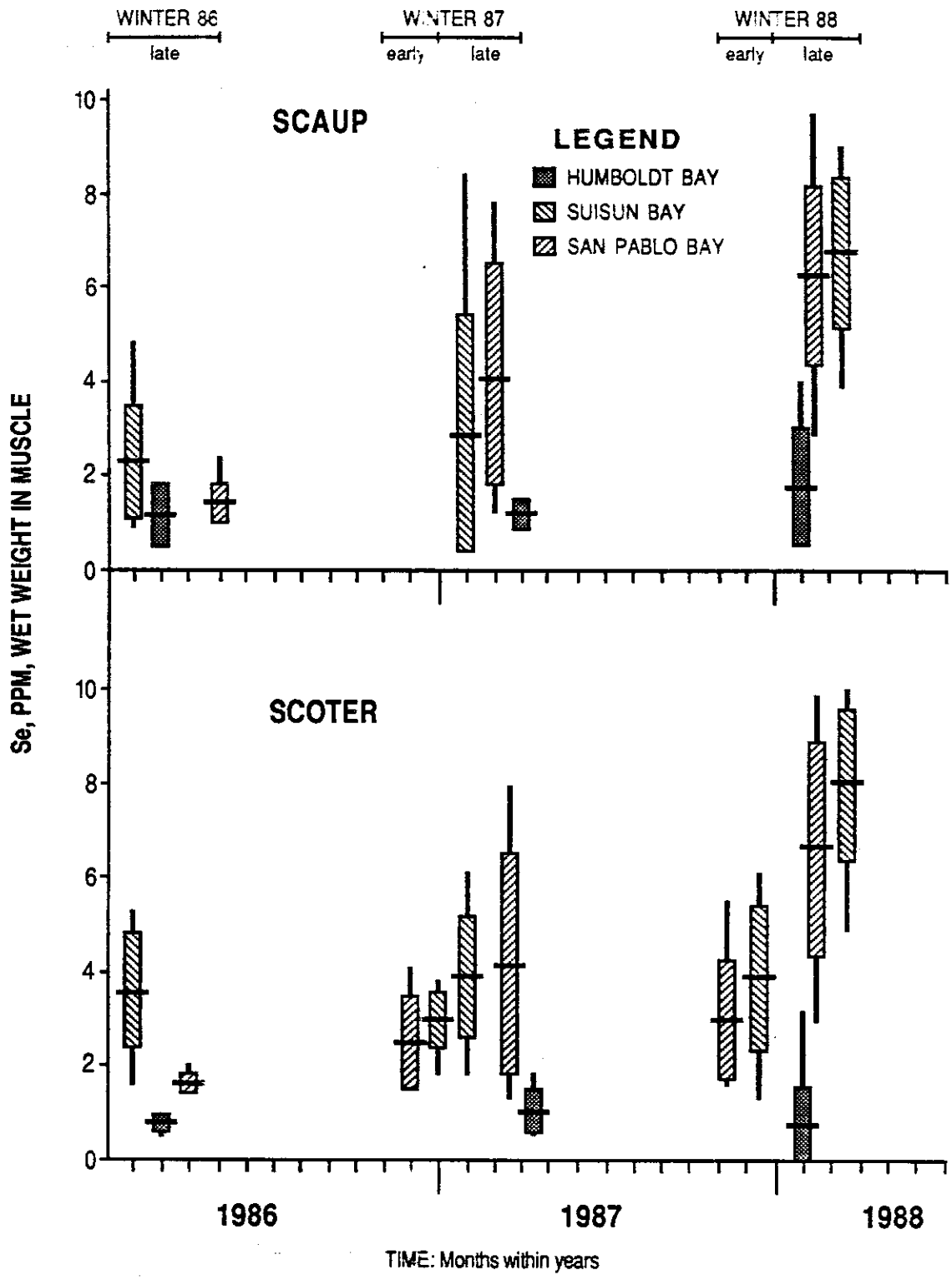


FIGURE 7. Selenium concentrations (arithmetic $\bar{x} \pm$ s. d., & range; ppm, wet weight) in muscle tissue of diving ducks during selected early and late winter periods of 1986 to 1988.

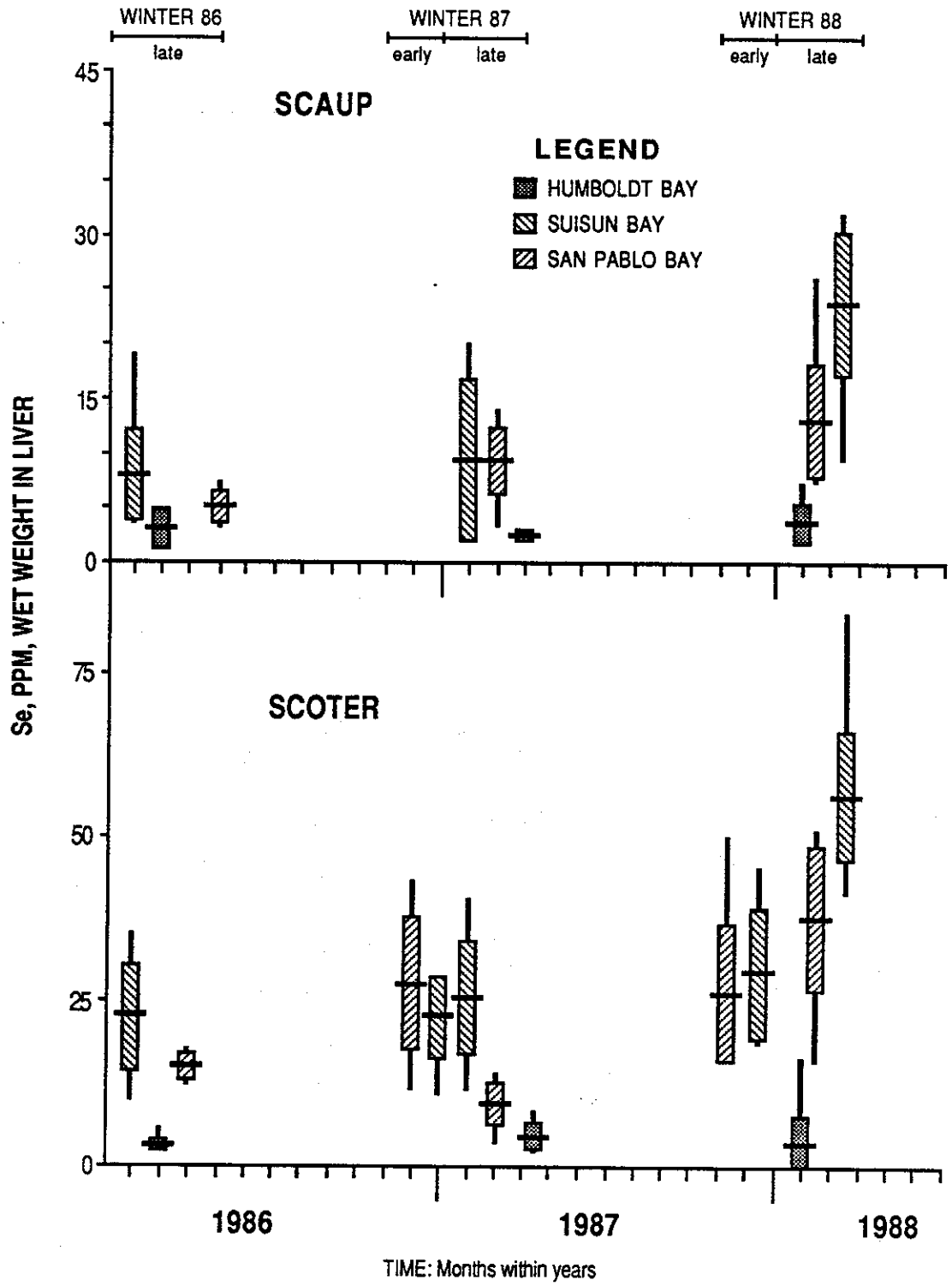


FIGURE 8. Selenium concentrations (arithmetic $\bar{x} \pm$ s. d., & range; ppm, wet weight) in liver tissue of diving ducks during selected early and late winter periods of 1986 to 1988.

increases in the Se concentration observed in late winter collections from one year to the next would most likely be due to increases in Se contamination within the Bay.

Scoters were collected in early winter of 1986-87 and 1987-88 from Suisun and San Pablo Bays. Mean selenium concentrations in muscle of early winter scoters were slightly higher in 1987-88 than in 1986-87 in both bays but the differences were not statistically significant (Table 11). Se concentrations in early winter scoter livers did not differ between years in either bay (Table 11). This comparison of only two years data would suggest that Bay Se levels are increasing and that depuration still exceeds uptake for surf scoters, but data from additional years are needed to reliably evaluate trends in scoter Se levels in early winter as well as late winter and to suggest which, if either, of these explanations is accurate. We also need data on annual changes in Se in Bay biota, sediments, and water to evaluate whether Se levels are increasing. We do not know what Se levels were in the Estuary more than eleven years ago (Risebrough et al. 1978) and the little information that is available does not give us a good basis for evaluating changes in Se concentrations over that time period.

To minimize within sample variability, this study has always attempted to collect adult male birds whenever possible. Juvenile, subadult, and female birds have been included occasionally to achieve required sample sizes. In these few cases, no systematic difference between sexes was apparent, however, the hypothesis of no difference between sexes had not been evaluated. In February 1988, ten female surf scoters were collected from Suisun Bay at the same time as the ten adult male scoters. Female scoters contained significantly less Se in muscle ($\bar{x}$=6.9 ppm compared to 8.9 ppm in males); Se concentration in scoter liver did not differ significantly between females ($\bar{x}$=53 ppm) and males (x=58 ppm). There is no data to suggest food habit differences between male and female scoters that might account for lower dietary uptake of Se in female scoters. A possible explanation for the disparity in muscle tissue Se levels between sexes is a difference in the way females metabolize, mobilize, or accumulate Se. Mobilization of Se into eggs is a probable mechanism for depuration of Se by females. Heinz et al. (1987), in feeding experiments with mallards, found adult males accumulated more Se in heart and liver tissue than did females in all but one experimental protocol, and postulated that elimination of Se through eggs was at least partly responsible. Selenium concentration differences between sexes are less likely to be observed in liver, particularly in Se enriched environments, since Se levels in liver change more quickly than those in muscle in response to recent exposure to selenium.

Scaup

Scaup were collected from San Pablo and Suisun bays only in late winter, thus we cannot determine if an increase of Se in

scaup occurred during the 1987-1988 winter. In February, 1988, mean Se concentrations in muscle of lesser scaup from Suisun Bay ($\bar{x}$=6.6 ppm) were not significantly higher than in greater scaup from San Pablo Bay ($\bar{x}$=6.0 ppm) (Table 8, Figure 5) whereas livers contained significantly more Se in scaup from Suisun Bay ($\bar{x}$=23 ppm) than San Pablo Bay ($\bar{x}$=12 ppm) (Table 8, Figure 6). Scaup from Suisun Bay and San Pablo Bay contained significantly higher Se concentrations in both tissues than scaup from Humboldt Bay ($\bar{x}$=1.5 ppm in muscle, $\bar{x}$=3.4 ppm in liver) (Table 8). Thus scaup, like surf scoters, contained above-background Se levels in late winter 1988, most likely as a result of Se uptake during the winter.

In discussing Se concentration in surf scoters, we noted that differences between scoters from Suisun and San Pablo bays, whether statistically significant or not, were small compared to the amount by which Se concentrations in birds from both areas exceeded those in scoters from Humboldt Bay. This relationship holds for Se levels in scaup muscle, which averaged at least four times higher in Suisun and San Pablo bays than in Humboldt Bay, but differed by only 10 percent between the former two locations (Figure 5). However, Se levels in the liver of scaup from Suisun Bay were two times those from San Pablo Bay which in turn were almost four times those from Humboldt Bay (Figure 6). Liver:muscle Se ratios of about 2:1 for San Pablo and Humboldt Bay scaup compared to 3.5:1 in Suisun Bay may suggest the possibility of a recent increase in bioavailable Se in Suisun Bay reflected in scaup liver Se levels but not yet in muscle. However, the difference in ratios may be species related since scaup from the two sites with the lower liver to muscle Se ratio were almost all greater scaup, whereas those from the latter location and with the higher ratio were lesser scaup.

To determine if Se concentrations in late winter scaup were increasing over recent years, 1988 scaup data were compared with analogous results from 1986 and 1987. An increasing trend may exist for scaup using Suisun and San Pablo bays. Analyses indicate significantly higher Se levels in 1988 than in 1987 or 1986 in Suisun Bay (Figure 7 and 8, Table 11). In scaup from San Pablo Bay, Se levels in muscle have increased significantly each year since 1986; liver concentrations also increased from 1986 to 1988 but 1987 and 1988 were not significantly different. Findings for Humboldt Bay indicated no significant

controlled experiments (Heinz et al. 1987), however, those results may not be relevant to other species. Similar studies probably could be done with scaup or surf scoters but none are proposed and results would not be obtainable soon.

Histopathological examination of internal organs of scaup and surf scoters collected from areas with elevated selenium levels was adopted for the second consecutive year, as the only viable approach to assessing potential selenium impacts on these birds. Tissue samples were obtained from both early-winter and late-winter birds. All bird specimens were examined for breast muscle atrophy.

Histological examination was conducted on individual specimens from Suisun Bay, chosen with prior knowledge of their tissue levels in order to select birds with the highest selenium loads which might be more likely to display a histological response to contamination. In 1988, selenium levels were highest in ducks from Suisun Bay. As a result, five early-winter and 35 late-winter birds were chosen for examination.

In general, conditions observed in sections of liver, spleen, and heart tissue were compatible with those expected from exposure to a normal environment, and there were no identifiable differences between the diagnoses of early- and late-winter birds. Livers had evidence of minimal to moderate pericholangitis in which cellular infiltrates consisted of lymphocytes, plasma cells, (in rare instances) heterophils and swollen macrophages. Observed in livers of most of the birds, these conditions are compatible with antigenic stimulation and are probably of parasitic origin. Minimal to moderate lymphoreticular hyperplasia in spleens from both sets of samples are probably of similar origin. Myocardial sections were normal except for several small foci of lymphocytic myocarditis and plasma cells in three samples, moderately congested myocardium in two cases, and one bird with myocardial vessels containing foci of intimal mineralization. These observations do not indicate unusually extensive tissue pathology associated with exposure to toxicants or from any other cause.

Four diving ducks, two surf scoters and two lesser scaup, were characterized in the field as having abnormal breast muscle development. These birds were from Suisun and San Pablo bays and did not contain higher liver selenium levels than levels in apparently normal birds from these sites. One bird of each species from Suisun Bay exhibiting abnormal breast muscle development did have the highest muscle tissue selenium levels for their species in the season in which they were collected (surf scoter, 11/87:6.1 ppm; lesser scaup, 2/88:9.0 ppm). However, birds collected in other seasons had equal or higher levels of selenium with no apparent effects. Therefore our data indicates that muscle atrophy probably was not caused by selenium but by other factors not necessarily related to toxicants. However, selenium may have produced the symptoms if

these birds were particularly sensitive to selenium and were affected by concentrations that were benign in most individuals.

SELENIUM IN COMPONENTS OF THE ESTUARINE ENVIRONMENT

During the fall and winter of 1987-1988, samples were collected several times from one site near Roe Island in Suisun Bay and four sites in San Pablo Bay (Figure 2). Selenium was measured in water, suspended particulate matter collected on 0.45um filters, zooplankton and phytoplankton collected in a 75um mesh net, benthic bivalves, and sediment. Samples were obtained from Suisun Bay in October and December 1987 and February 1988 and from San Pablo Bay in November 1987 and February 1988. For comparison, similar sampling was conducted at Humboldt Bay in January 1988. Except for benthos and sediment, samples were collected on both a low and a high tide.

Table 12. Selenium concentrations in water (filtered), sediment, suspended particulates, plankton, benthic bivalves, and diving ducks from Suisun, San Pablo and Humboldt Bays, 1987-1988.

Location/Date	Tide	Water (PPB)	Sediment (ppm,dry wt.)	Suspended Particulates (ppm,dry wt.)	Plankton[1] (ppm,dry wt.)	Benthic Bivalues[2] (ppm,dry wt.)	Scoter (ppm,dry wt.)	Scaup (ppm,dry wt.)
Suisun Bay, Roe Is.								
10-14-87	L	0.12		0.49	0.13			
	H	0.17		0.53	-		14.03(M)[3]	-
	mean:	0.14	<0.04	0.51	-	4.6	99.63(L)[4]	-
12-02-87	L	0.09		0.39	<0.20			
	H	0.13		0.36	<0.01			
	mean:	0.11	<0.06	0.38	-	3.3		
2-22-88	L	0.19		0.35	0.20			
	H	0.21		<0.01	<0.01		28.93(M)	24.57(M)
	mean:	0.20	<0.06	-	-	3.4	192.89(L)	83.74(L)
San Pablo Bay								
11-23-87								
Petaluma River	L	0.14		0.36	<0.08			
	H	0.11		0.37	<0.01			
	mean:	0.12	0.20	0.36	-	1.2		
China Camp	L	0.19		0.33	<0.20			
	H	0.06		0.32	<0.20			
	mean:	0.12	0.25	0.32	<0.20	2.3		
Castro Cove	L	0.13		0.35	0.26		11.24(M)	-
	H	0.14		0.29	0.20		83.51(L)	-
	mean:	0.14	0.24	0.33	0.23	1.1		
Wilson Pt.	L	0.05		0.31	<0.20			
	H	0.14		0.36	<0.20			
	mean:	0.10	0.30	0.34	<0.20	0.65		
2-25-88								
Petaluma River	L	0.17		0.64	<0.20			
	H	0.15		0.65	<0.10			
	mean:	0.16	0.29	0.64	-	1.3		
China Camp	L	0.15		0.42	<0.10			
	H	0.11		0.42	<0.10			
	mean:	0.13	0.29	0.42	<0.10	-		
Castro Cove	L	0.12		0.48	<0.20		23.89(M)	23.34(M)
	H	0.14		0.38	<0.20		135.08(L)	46.51(L)
	mean:	0.13	0.17	0.43	<0.20	0.5		
Wilson Pt.	L	0.17		0.45	<0.20			
	H	0.14		0.47	0.10			
	mean:	0.16	0.30	0.46	-	-		
Humboldt Bay								
1-29-88	L	0.05		0.37	<0.20			
	H	0.06		0.27	<0.20		2.67(M)	6.57(M)
	mean:	0.06	0.25	0.32	<0.20	2.0	11.87(L)	13.57(L)

1/ <0.XX indicates value less than the listed detection limit, limits varied with amount of analyzable sample.
2/ Arithmetric mean of all species collected.
3/ Arithmetric mean of muscle tissue.
4/ Arithmetric mean of liver tissue.

respect to tide, although the higher Se concentrations were always in low tide samples at both western San Pablo Bay sites. Tide had the smallest effect on Se concentration in Castro Cove.

We did not observe the expected effect of location on dissolved Se among the four sites. Averaged for both tides, the Petaluma River Channel, China Camp, and Castro Cove sites all contained about 0.13 ppb Se compared to 0.10 ppb at Wilson Point in fall, 1987. In winter 1988, Se concentrations were 0.16 ppb at the Petaluma River and Wilson Point sites compared to 0.13 ppb at China Camp and Castro Cove. Averaged over both seasons, dissolved total Se concentrations were essentially uniform throughout San Pablo Bay. Complex circulation patterns produced by the combined actions of river outflow, tides, winds, and water density apparently disperse effluents from point sources resulting in a reasonably homogeneous environment with respect to the chemical constituents of discharges. Non-motile biota such as benthic mollusks may experience particularly high Se exposure if situated very close to a point source discharge, however, potentially significant exposure to Se may also occur in benthos miles away from discharge points if currents transport effluent components to those sites.

Water collected from Humboldt Bay in January 1988 contained 0.05 ppb and 0.06 ppb dissolved total Se on low and high tide, respectively. Only two of 16 water samples from San Pablo Bay, and none from Suisun Bay contained Se concentrations as low as Humboldt Bay and maximum concentrations (0.21 ppb in Suisun Bay) were 3 to 4 times higher than Humboldt Bay. Dissolved Se concentrations of 0.05 ppb to 0.06 ppb indicate there is no Se enrichment of Humboldt Bay waters from anthropogenic sources. Because the drainage area is small and freshwater inflow is limited, Humboldt Bay water quality is strongly influenced by tidal exchange of seawater. Thus it is not surprising that the concentration of dissolved Se in Humboldt Bay is similar to dissolved total Se measurements of approximately 0.08 ppb in water samples taken from the northeastern Pacific Ocean (Cutter and Bruland 1984).

The concentration of distinct chemical forms or species of selenium was determined in water samples collected from Humboldt Bay in January 1988 and from Suisun and San Pablo bays in February 1988. Humboldt Bay samples from previous years and Suisun and San Pablo Bay samples from October and November 1986 were analyzed only for dissolved total Se because nitric acid was used instead of hydrochloric acid to preserve them and all forms of Se had been oxidized to selenate (Se VI). Humboldt Bay water was distinguished by the high percentage of selenate

detectable Se -II & 0. Se VI:Se IV ratios were 5:1 and 2:1 at low and high tide, respectively.

Water at Wilson Point contained a higher proportion of Se VI and a lower proportion of Se IV than the effluent from the nearby Union Oil Refinery. Neither the bay water nor the refinery effluent contained measurable Se -II & 0. These results suggest that Union Oil's discharge is not the dominant source of Se in eastern San Pablo Bay.

Most water samples from other San Pablo Bay sites contained proportionally less Se VI at low tide than the sample from Wilson Point; the proportion of Se VI was more similar among San Pablo Bay sites at high tide. Se VI:Se IV ratios ranged from about 1.4:1 to 2.9:1; when the ratio differed between tides it was greater on high tide than low tide, the opposite of what we observed at Humboldt Bay and at Wilson Point in San Pablo Bay. The only significant amount of Se -II & 0 at San Pablo Bay sites was 0.07 ppb (about 40 percent of total Se) at the Petaluma River Channel at low tide, suggesting the Petaluma River may have been the source. Additionally, the Petaluma River site had a relatively high proportion of Se VI, similar only to levels found at Wilson Point. In San Pablo Bay, proximity to sources and the distributional effects of currents appear to combine to determine Se concentrations in water at any location.

Suisun Bay water contained the highest concentrations of dissolved total Se (0.19-0.21 ppb) measured in the Estuary, suggesting enrichment from local sources. The Se species composition in Suisun Bay was unique among all bay sites, with roughly equal proportions of Se IV, Se VI, and Se -II & 0 at low tide and a 1:1:2 ratio of species at high tide. No other sites had substantial concentrations of Se -II & 0 on both tidal stages, suggesting Se -II & 0 input near the sample site. Cutter (1987) reported about 12-13 ppb Se -II & 0 in two (Shell Oil and Tosco Corp.) of the several refinery discharges in western Suisun Bay. Of interest, but unknown significance, is the fact that 12-13 ppb Se -II & 0 represents about sixty percent of the total Se in the Tosco discharge but only about nine percent of the total Se discharged by Shell Oil. The Shell Oil effluent contained 132 ppb dissolved Se of which about 73 percent was Se IV. The Exxon refinery discharge to Suisun Bay contained about half the concentration of total Se as Shell Oil, but like Shell, contained a high proportion (85%) of Se IV. Shell and Exxon contributed the largest Se loads of the refineries sampled in western Suisun Bay. Nevertheless, our water samples from Roe Island did not reflect the high proportion of Se IV typical of the Shell Oil and Exxon discharges. Instead the Se species occurred in relative proportions closer to those found in the Tosco Corp. effluent. Se speciation in water at our sampling site near Roe Island, particularly the predominance of Se -II & 0, suggests a stronger influence from the nearby Tosco refinery than from Shell Oil further downstream or Exxon across the Bay.

In addition to local Se sources within the estuary, input of Se from agricultural drainwater discharged upstream needs to be considered. Previous investigations (e.g. Johns and Luoma 1987) concluded Se from subsurface drainage discharged into the San Joaquin River did not affect bioaccumulation in the lower Estuary because of dilution from low-selenium tributaries and the removal of most San Joaquin River flows from the Delta by State and Federal water project diversions. Our limited data on Se speciation in Suisun Bay support their conclusions. Se in the San Joaquin River and the alkaline drainwater occurs mostly as Se VI (Cutter 1987; Deverel et al., 1984), thus Se VI would be the predominant component of total Se in the western Delta and Suisun Bay if the rivers were contributing Se to the Estuary. Instead Suisun Bay samples contained less than 0.06 ppb Se VI, only thirty percent of the 0.20 ppb average concentration of total Se in Suisun Bay, and the lowest proportion of the three forms of Se measured. Continued studies of Se in the Estuary being conducted by Cutter may further clarify the behavior of Se.

Suspended Particulate Selenium

Selenium associated with suspended particulate material was measured in samples collected from Suisun and San Pablo bays at the same sites and times as water samples. The particulate material is that which passed through a 75 um plankton net and was collected on a 0.45 um filter. Suspended particulate Se is either adsorbed to or incorporated in this mixture of organic and inorganic material.

Suspended particulate Se ranged from <0.01 ppm to 0.65 ppm (dry weight) in Suisun and San Pablo bays (Table 12). In Suisun Bay particulate Se was higher in October 1987 ($\bar{x}$=0.51 ppm) than in December ($\bar{x}$=0.38 ppm) or the following February ($\bar{x}$ approx. 0.18?) whereas in San Pablo Bay it was higher in February 1988 ($\bar{x}$=0.48 ppm) than in November 1987 ($\bar{x}$=0.34 ppm). Between the two bays, higher Se concentrations in suspended particulates occurred in Suisun Bay in the fall and in San Pablo Bay in the winter. Tidal stage did not affect particulate Se.

Unexpectedly, the highest Se concentration in suspended particulate samples from the Estuary was at the mouth of the Petaluma River Channel in northwestern San Pablo Bay. Among San Pablo Bay sites, this was the farthest from known point sources of Se within San Pablo Bay. Current patterns and the composition of the suspended material may have influenced this result, however the possibility of Se sources in the Petaluma River drainage basin should be investigated.

Our measurements of suspended particulate Se are in the same range as results reported by Cutter (1987) for the northern reach of the Estuary in April and September 1986. He reported Se on a volumetric basis (ug Se per liter of water filtered, ppb) with results ranging from about 0.005 ppb to 0.030 ppb. Converted to the units used by Cutter, our findings ranged from 0.004 ppb to 0.05 ppb in San Pablo Bay in February 1988.

Cutter characterized the suspended particulate fraction of Se as a small part of the total water column Se and discounted its importance in his evaluation of Se behavior and loading to the Estuary. Nevertheless, we believe Se concentrations in suspended particulates are high enough to have a potentially significant effect on Se intake by filter-feeding benthic organisms in the Bay. Benthic bivalves containing Se are then eaten by some fish and diving ducks which accumulate Se in their tissues.

Selenium in Phytoplankton and Zooplankton

We attempted to determine the concentration of Se in phytoplankton and zooplankton collected in a 75 um net from Suisun and San Pablo bays. Because primary and secondary productivity in the Estuary was low during the sampling periods, it was difficult to collect enough plankton to measure Se concentrations with confidence. The lower limit of detection was inversely related to the amount of plankton collected, and ranged from 0.01 ppm to 0.20 ppm for largest and smallest samples, respectively. Thus, usable data were obtained from only five of twenty two sampling attempts.

Se concentrations ranged from 0.10 ppm to 0.26 ppm (ug/g, wet weight) (Table 12). Percent moisture was measured only in two

Selenium concentrations in Suisun Bay sediments have not changed since the U. S. Geological Survey (USGS) began sampling there in 1984. Johns and Luoma (1987) summarized the USGS data on Se in sediments for several sites in Suisun Bay, where selenium concentrations ranged from 0.2 ppm to 0.4 ppm (ug/g, dry wt.), very similar to concentrations we measured in San Pablo Bay. We measured lower Se concentrations in Suisun Bay

in organic composition of sediment samples from each of the two studies. Though we did not directly measure the organic content of our sediment samples, those from San Pablo Bay, which appeared to contain more organic material, had greater concentrations of Se than Suisun Bay samples of apparently lower organic content.

Selenium in Benthic Bivalve Mollusks

Benthic bivalve mollusks were sampled in Suisun and San Pablo bays at the same time other types of samples were collected. The freshwater clam, Corbicula fluminea, and a recently established exotic clam species of the genus Potamocorbula were collected near Roe Island in Suisun Bay. From San Pablo Bay, samples of a small mussel, Musculus senhousia were collected from three of four sites in November 1987. For unknown reasons, Musculus populations in San Pablo Bay were almost completely eliminated during the winter, thus no Musculus were collected in February, 1988. Potamocorbula were sampled twice at the Petaluma River channel entrance while Japanese littleneck clams, Tapes japonica, were collected from Castro Cove in both seasons.

Corbicula samples from Roe Island in Suisun Bay contained from 5.5 ppm to 7.3 ppm Se (dry weight) (Table 9), the highest concentration in any bivalve mollusk tested. Corbicula collected from Suisun Bay from January through April 1987

and 1.4 ppm Se in November 1987 and 1.3 ppm Se in February 1988. These concentrations in Potamocorbula are in the middle of the range of concentrations found in Musculus from San Pablo Bay and similar to concentrations measured in Potamocorbula from Suisun Bay. No seasonal variation in Se was indicated. Tapes japonica from Castro Cove contained 0.54 ppm and 0.52 ppm Se in November 1987 and February 1988, respectively, also indicating no seasonal change. Tapes had only about one third the Se concentration of Musculus at the same site. Diving ducks fed on all five bivalve mollusk species in the bays where the mollusks occurred (Table 10 and Appendix J). Potamocorbula were found in 79 percent of scaup and 73 percent of surf scoters collected from Suisun Bay. Corbicula were also eaten by 2% of the scaup and 13% of the scoters we collected from Suisun Bay, but were much less important in 1987-1988 than in 1986-1987 when 95 percent of scaup and 83 percent of surf scoters contained Corbicula. The recently established Potamocorbula apparently has supplanted Corbicula as the predominant food for diving ducks in Suisun Bay. Compared to diving ducks feeding mainly on Corbicula as scaup and scoters did in Suisun Bay during 1986-1987, ducks feeding extensively on Potamocorbula in 1987-1988 may have had lower dietary exposure to Se since Potamocorbula contained less Se than Corbicula. As mentioned above, differences in sample

Corbicula from Suisun Bay (Table 9). The differences in sample preparation again affect direct comparisons between Humboldt Bay collections (tissue only) and all species but Corbicula from Suisun and San Pablo bays (whole body samples). Humboldt Bay bivalves have more selenium on a dry weight but less on a wet weight basis than Potamocorbula, Musculus and Tapes from Suisun and San Pablo bays (Table 9). Given these differences in wet weight vs. dry weight comparisons between bivalves collected from the two areas, it is probable that if analyses of Humboldt Bay bivalves had been done on whole samples

including shells, rather than on tissue alone, they would also have had low selenium concentrations on a dry weight basis. No species was collected both at Humboldt Bay and the San Francisco Bay system again confounding direct comparisons. Furthermore, the relevance of Se concentrations in the three clams species we were able to collect from Humboldt Bay to diving ducks there is probably minimal, since food habit data indicate different species of clams, mussels, and snails dominated their diet.

Bioaccumulation of Selenium in the Food Chain

Diving ducks wintering on Suisun and San Pablo bays have Se in their tissues at concentrations as high as 285 ppm (dry weight) even though bay waters generally contain about 0.1 ppb to 0.2 ppb dissolved total Se. Animal tissues have been found to contain Se concentrations in the range of 100 to greater than 30,000 times that found in their aquatic environment (Lemly & Smith 1987) because Se can be accumulated, increasing its concentration in individual plants or animals above background levels. At successive levels in the food chain, consumer organisms eventually build up higher Se concentrations than contained in the organisms they consume, thus biologically magnifying the element. The terms bioconcentration, bioaccumulation, and biomagnification are often used interchangeably although each refers to a slightly different process. Regardless of the terminology, however, the significant result is potentially harmful amounts of Se in higher trophic level species, including humans.

The connection between the diving ducks and the Se found in Bay water includes benthic invertebrates (clams, mussels, snails etc.) that are eaten by the ducks and the plankton and suspended particulate matter strained from water by these predominantly filter feeding mollusks. The role of selenium in sediment is unknown but may affect uptake by ducks which disturb and probably ingest some sediment as they feed on the bottom. Direct uptake of Se from water is probably not important to diving ducks.

The ratio of the Se concentration at one trophic level to that at the next lower level indicates the degree to which Se has been bioaccumulated by the consumer organisms. Se levels reached in ducks probably result from the bioaccumulation of Se as it is passed up the food chain. Concentrations expressed on a dry weight basis were used for this purpose since wet weight

values were not always available. Average concentrations for species or time periods at each collection location were used to represent the general relationship between trophic levels. Extreme bioaccumulation factors calculated from, for example, the highest individual duck tissue Se concentration and the lowest associated Se concentration in a single water sample were not presented, since the relative magnitude of ratios between successive trophic levels was of greater interest than the specific ratios themselves. Also, because of uncertainty about the exact location of feeding and selection of food organisms by individual ducks, ratios for individual birds are not very useful. Bioaccumulation factors on a dry weight basis were recomputed for the data presented in Table 8 and Figure 7 of last year's report (White et al. 1988) and used for comparison with this year's results.

Selenium was about 750,000 to 1.2 million times more concentrated in the liver of diving ducks than in the water of Suisun and San Pablo bays (Figure 9), versus a bioaccumulation factor of 100,000 to 650,000 measured in January and April, 1987. Diving duck muscle tissue Se concentrations averaged about 135,000 to 170,000 times that in Bay water, compared to bioaccumulation factors of 43,000 to 93,000 measured in last year's study. Bottom-dwelling clams and mussels, important food items for diving ducks, had Se concentrations in the range of 3,000 to 30,000 times Bay water levels (vs. 25,000 to 30,000 in January and April, 1987). On the basis of limited data, samples consisting of a combination of phytoplankton and zooplankton contained about 3,000 to 20,000 the Se concentration of water. Selenium associated with suspended particulate material was 1700 to 5800 times more concentrated than Se in water. Last year's program did not collect data on plankton or suspended particulates so no comparisons can be made. Se was 1,000 to 2,700 times more concentrated in sediment than in bay waters, which is comparable to the concentration factors measured last year of 260-2,400 times.

The bioaccumulation factors for Se at higher trophic levels in the food chain , for example the comparison of Se in duck tissues with Se in duck food items, varied by a factor of ten. Even the higher bioaccumulation factor of about 200 times between liver from Suisun Bay scoters and their major food item, Potamocorbula, represents a small percentage of the overall biomagnification through the food chain from water to bird tissue. Last year's study measured bioaccumulation factors from benthic bivalves to diving ducks in the range of 1.5 to 26, levels similar to, but not quite as high as were measured this year. Clams and mussels accumulate Se only up to about 16 times its concentration in the plankton and suspended particulate matter that these mollusks strain from the water for their nutrition. Some benthic invertebrates contained lower concentrations of Se than the suspended particulate matter at the site, indicating no bioaccumulation between trophic levels.

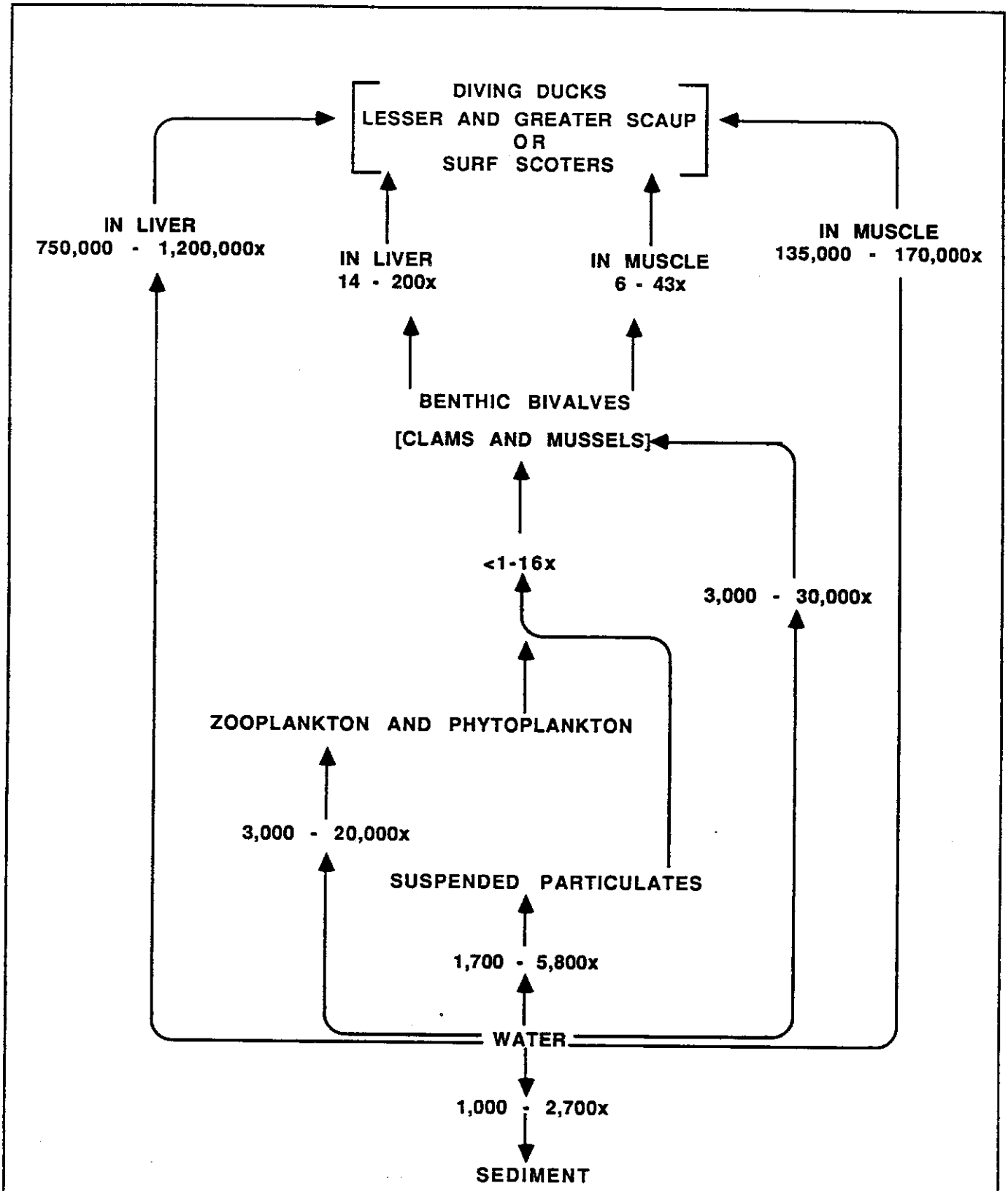


FIGURE 9. Bioaccumulation factors between trophic levels in the food chain of diving ducks, Suisun and San Pablo Bays, 1987-1988. Factors were derived from mean dry weight concentrations of samples shown in Table 12.

The largest amount of bioaccumulation is accomplished by primary and secondary producers, the phytoplankton and zooplankton in the Estuary. Our analyses indicated plankton concentrate Se from water by approximately 3,000 to 20,000 times. This relationship needs further examination, since samples were an unsorted mixture of phytoplankton and planktivorous zooplankton, thus representing two food chain links. Utilization of suspended particulates by plankton also introduces a second possible accumulation step affecting Se levels in plankton, however, our limited sampling indicates that all of the plankton samples had less Se on a dry weight basis than concurrently collected suspended particulate samples. Though bioaccumulation factors measured between diving ducks and lower levels of the food chain were 2 to 10 times greater this year than last, it isn't possible to say whether this difference is significant or meaningful based on our data alone.

Bay sediments contained 1,000 to 2,700 times more Se than Bay

SELENIUM IN ADULT ANADROMOUS FISH IN THE ESTUARY

Striped Bass

The average Se concentration in the muscle tissue of ten adult female striped bass collected from the Sacramento-San Joaquin Estuary in spring 1988 was 0.38 ppm, wet weight (Table 13). Concentrations in individual fish ranged from 0.28 ppm to 0.48 ppm. The 1988 average Se concentration was between the ten fish average of 0.34 ppm in 1986 and 0.43 ppm in 1987 (White et al. 1988). Thus although striped bass from the Delta contained significantly higher muscle Se concentrations in 1987 than 1986, data for 1988 do not support the hypothesis of an increasing trend in Se in striped bass from the Estuary.

Although striped bass from Success Lake (Tulare Co.) contained an average 0.14 ppm in 1987 (White et al. 1988), significantly less than bass from the Sacramento-San Joaquin River system, Se levels in striped bass in the estuarine population are less than the median Se concentration (0.42 ppm) reported for fish tissue nationwide (Lowe et al. 1985). There is no direct evidence that Se has had an impact on striped bass in the Estuary, although definitive studies are lacking. Se levels in striped bass from the Estuary present no threat to human consumers according to current evaluations of Se risks to human health by the California Department of Health Services.

White Sturgeon

The Se concentration in muscle tissue of fourteen white sturgeon collected from San Pablo Bay in spring 1988 averaged 1.5 ppm, wet weight (Table 13), 21 percent and 42 percent less than average concentrations in 1986 (1.9 ppm) and 1987 (2.6 ppm), respectively. Concentrations in individual sturgeon ranged from 0.51 ppm to 3.3 ppm. The lowest concentration in 1988 was about half the minimum levels measured in 1986 and 1987 (1.1 ppm) in sturgeon from San Pablo Bay, while the maximum Se concentration in 1988 was about 20 percent less than in 1986 (4.0 ppm) or 1987 (4.3 ppm).

White sturgeon Se concentrations increased significantly from 1986 to 1987, however, as with striped bass, concentrations were lower in 1988, indicating no trend for Se in white sturgeon.

The muscle tissue concentrations of selenium in white sturgeon was negatively related to size (Figure 10), but the correlation is rather weak (r^2=0.29). The results, based on only 14 fish suggest that older and larger sturgeon have lower concentrations of selenium in their tissues. Neither collection location nor differential food habits can be used to explain these size related differences in selenium concentrations, though the latter cannot be ruled out as a possible explanation. All fish samples were from San Pablo Bay and food habits studies (McKechnie & Fenner 1971) do not

Table 13. Selenium concentrations in muscle tissue of adult striped bass (*Morone saxitilis*) and white sturgeon (*Acipenser transmontanus*) from the Sacramento-San Joaquin Estuary, 1988. Concentrations in ppm, wet weight.

Species/Site	N	Geometric $\bar{x}$	Arithmetic $\bar{x} \pm$ S.D.	Range
Striped Bass;				
Antioch, San Joaquin R.	5	0.37	0.37 ± 0.07	0.28 - 0.48
Clarksburg, Sacramento R.	5	0.40	0.40 ± 0.05	0.33 - 0.47
White Sturgeon; San Pablo Bay	14	1.36	1.48 ± 0.81	0.51 - 3.3

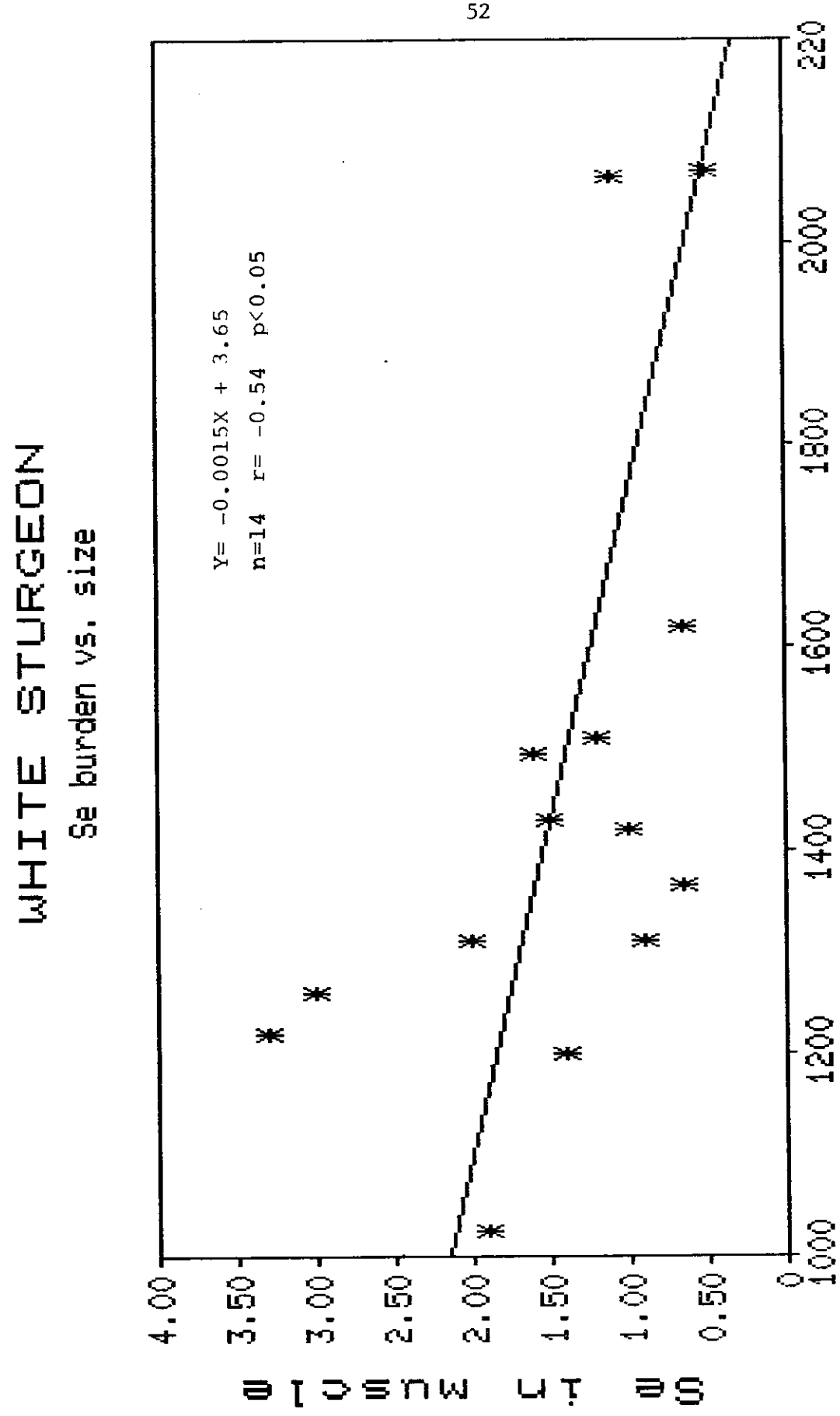


Figure 10. The relationship between size and selenium concentration of muscle tissue in white sturgeon collected from San Pablo Bay in spring 1988.

evaluate size related differences in diet in adult, legal sized fish in the size range we collected. Other studies do suggest dietary differences between adult and juvenile sturgeon but were based solely on juveniles captured in the fresh waters of the Sacramento-San Joaquin Delta where prey species differ from those in San Pablo Bay (Radtke 1966).

White sturgeon are an important sport fish. Because they are long lived (legal-sized sturgeon are at least eight years old) and feed on the same type of bottom-dwelling organisms (e.g. clams and mussels) eaten by diving ducks, we might expect dietary uptake and accumulation to produce above-average Se concentrations in sturgeon tissue. Average Se concentration in 1988 was over 3.5 times the nationwide median Se concentration (0.42 ppm) in tissues of various fish species from 1978 to 1981 (Lowe et al. 1985). The California Department of Health Services has evaluated sturgeon Se data for 1986 through 1988. Although a few individual fish have Se levels in the range that generates concern, the Department of Health Services has concluded the overall level of risk does not warrant an advisory recommending restrictions on human consumption of sturgeon.

SELENIUM IN BIOTIC AND ABIOTIC COMPONENTS OF THE LOWER SAN JOAQUIN RIVER AND SELECTED VALLEY-FLOOR TRIBUTARIES

Six sites were selected representing a range of influence from Se in agricultural drainwater on San Joaquin Valley waterways (Figure 4). The San Joaquin River at State Highway 165 (Lander Avenue) is upstream from Mud Slough and Salt Slough, San Joaquin River tributaries used in recent years as conduits for selenium-enriched subsurface drainage from irrigated agriculture in portions of the western San Joaquin Valley. At sites in the San Joaquin River downstream of the Merced River and the Tuolumne River (San Joaquin River at Maze Blvd.), the effects of agricultural drainage on water quality and biota are influenced by dilution and Se cycling among components of the river environment. Camp 13 Ditch is an earthen channel used to supply water for irrigation and to remove drainwater in the South Grasslands. The character of its flows varies seasonally and it is occasionally dry.

Beginning September 1987, samples of fish and sediment were collected bi-monthly; filtered (0.45u) water, suspended particulate matter, and plankton sampling began in November. Sampling continued through May 1988.

Selenium Dissolved in Water

Camp 13 Ditch contained the highest dissolved Se concentrations, ranging from 62 ppb to 104 ppb in January, March, and May 1988 samples (Figure 11). At the five remaining sites, dissolved Se in November ranged from less than 1 ppb in the San Joaquin River at Lander Avenue to 3.3 ppb in Salt Slough. Concentrations of dissolved Se were higher in January at all sites, increasing by almost 6 times the November level in Salt Slough (to 19 ppb) and by a smaller amount elsewhere. Both Mud Slough and Salt Slough contained relatively high dissolved Se in March (20 ppb and 16 ppb, respectively) and levels in the San Joaquin River downstream were also higher than in January (10 ppb at the Merced River and 5.2 ppb at Maze Blvd.) while upstream at Lander Avenue the level was lower (< 1 ppb) than in January (5 ppb). In May samples, dissolved Se was still < 1 ppb at Lander Avenue and was lower at the other 4 sites than it had been in March. The most significant reduction was in Mud Slough where dissolved Se had declined from 20 ppb in March to 2.4 ppb in May.

From these data it is apparent that Se input through Salt and Mud sloughs provide the dominant influence on dissolved Se levels in the San Joaquin River. Changes in the management of subsurface drainwater since inflow to the San Luis Drain was stopped and Kesterson Reservoir was closed have probably increased the discharge of Se to Salt Slough, as consistently high levels from January through May indicate. Discharge of Se into the San Joaquin River upstream of Mud and Salt sloughs is indicated by the finding in January 1988 of 5 ppb Se in water at the Lander Avenue site where water samples in all other months contained less than 1 ppb Se.

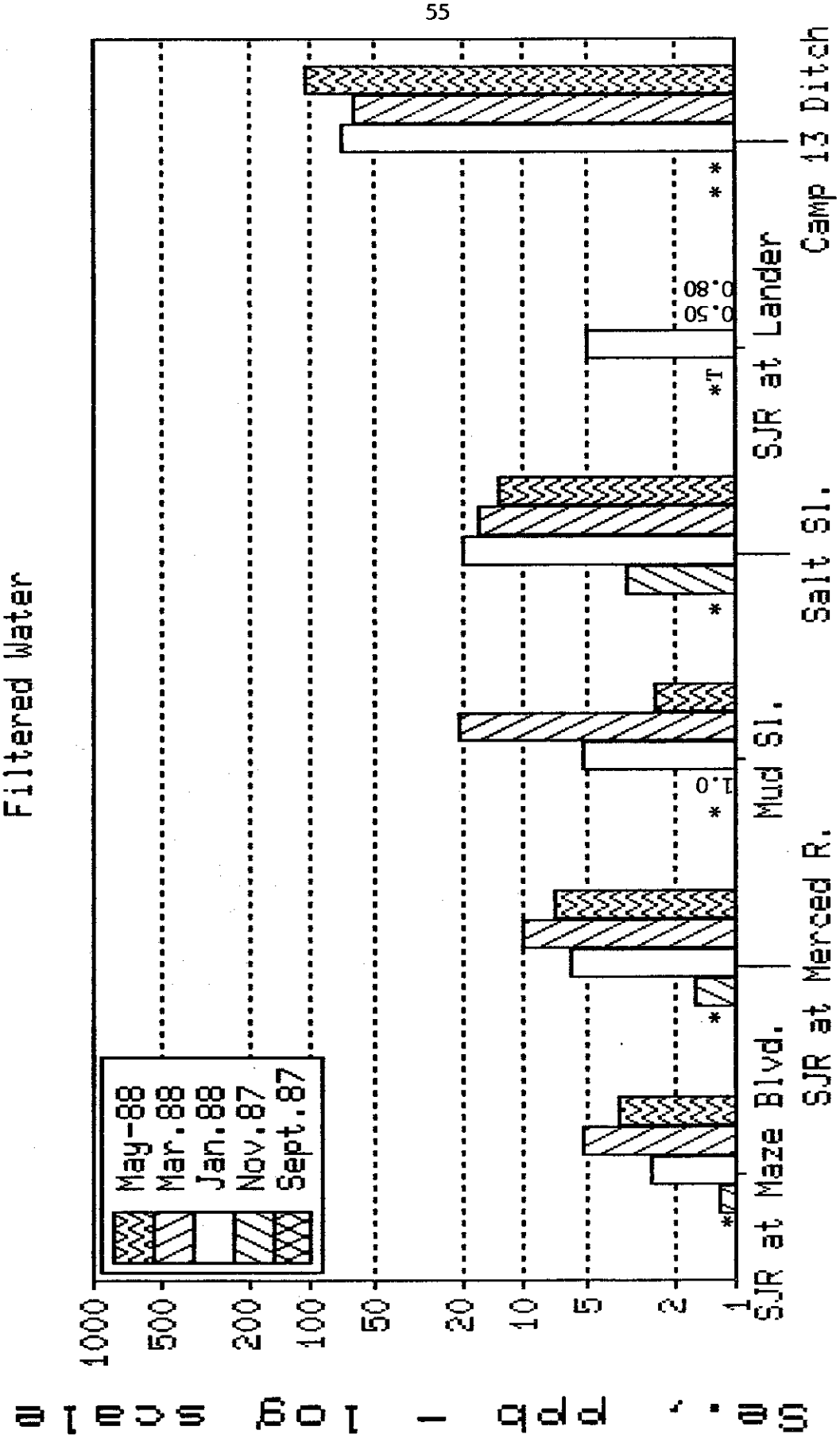


Figure 11. Selenium concentrations (ppb=ug/kg, plotted on a $\log_{10}$ scale) in filtered water samples collected at sites in the San Joaquin Valley, 1987-1988. Asterisks, "*", indicate months when no samples were obtained; "T" indicates trace amounts were detected; numbers indicate values too small to plot on the figure.

Because of Se input from Mud and Salt sloughs, dissolved Se concentrations downstream at the San Joaquin River sites near the mouth of the Merced River and near Maze Blvd. consistently were higher than upstream at Lander Avenue. More specifically, in January, March, and May the Se levels in the tributary providing the primary Se input (Mud Slough or Salt Slough) and at the Merced River and Maze Blvd. sites maintained approximately a 4:2:1 ratio with about a 50 percent reduction in the dissolved Se concentration in the river reach between these sites. Dilution by low Se water from the Merced and Tuolumne rivers combined with the cycling of Se within the river environment through chemical, physical and biological processes (Lemly and Smith 1987) produce progressively lower concentrations of dissolved Se moving downstream from tributaries containing Se. Agricultural drainwater management practices strongly influence the concentration of Se in San Joaquin River tributaries such as Salt and Mud sloughs while physical, chemical, and biological processes combine to moderate the effect of Se input from drainwater on the dissolved Se levels in the lower San Joaquin River.

Suspended Particulate Selenium

The concentration of Se associated with suspended particulate matter ranged from 0.91 ppm (ug/g dry wt.) to 2.7 ppm (Figure 12). In general, suspended particulate Se was higher at sites with high levels of dissolved Se and lower at the San Joaquin River site upstream of Salt and Mud sloughs and at the farthest downstream site, at Maze Blvd. Particulate Se concentrations were more stable through time, varying by no more than 2.25x at any site, than dissolved Se levels which changed by as much as 10x during the sampling period (Figure 11).

Factors besides dissolved Se concentrations affect suspended particulate Se levels. In two samples of suspended particulate matter from Camp 13 Ditch, Se concentrations (2.4 ppm, 1.6 ppm) were about 25-35x dissolved levels of 70 ppb and 62 ppb, respectively. In contrast, a particulate Se concentration of 1.2 ppm was measured in the San Joaquin River at Lander Avenue

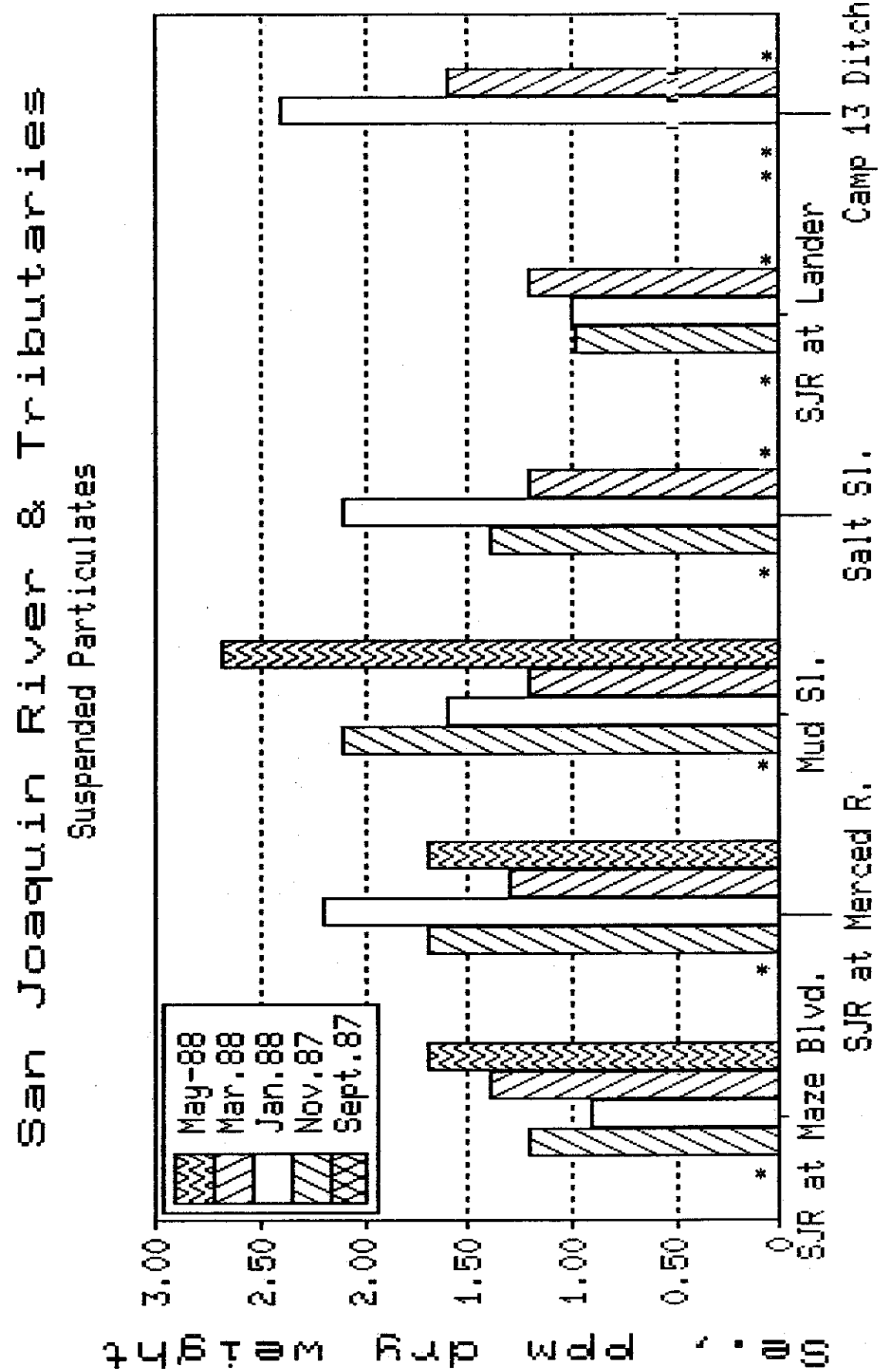


Figure 12. Selenium concentrations (ppm, dry weight) in suspended particulate samples collected at sites in the San Joaquin Valley, 1987-1988. Asterisks, "*", indicate months when no samples were obtained.

combined with the changes that occurred in solution while they drifted downstream to where they were finally collected.

Selenium in Plankton

The concentration of Se in plankton samples ranged from 0.32 ppm (ug/g, dry wt.)in the San Joaquin River at Lander Avenue to 8.4 ppm in Camp 13 Ditch (Figure 13). Most samples contained less than 3 ppm Se. Plankton Se was consistently lowest at the Lander Avenue site on the San Joaquin River and sites were ranked generally in the same order on the basis of plankton Se concentrations as when ranked by dissolved or particulate Se. However, the dependence of plankton Se on other factors besides dissolved Se is obvious from the measurement of 1.2 ppm to 1.4 ppm Se in plankton at dissolved Se concentrations ranged from 1.2 ppb to 104 ppb. Many factors affect primary production including temperature, nutrient availability, residence time of the water mass, turbidity, and incident solar radiation. The lack of a clear relationship between Se in plankton and dissolved Se may be due to the overriding effects of these factors on productivity and rates of Se uptake. It may also be due to the fact that Se concentrations in plankton reflect the integrated effects of conditions upstream through which the organism passed on its way to the point of collection.

Toxic effects may result in fish and wildlife whose food items contain Se concentrations between 3 ppm to 8 ppm (dry weight) or more (Lemly and Smith 1987). None of the plankton or suspended particulate samples we collected, which represent potential food items, contained Se at these levels, but biomagnification of Se by planktivores to higher concentrations than found in plankton may constitute a threat to piscivorous fish and birds.

Selenium in Sediment

Selenium concentrations in benthic sediment ranged from less than 0.04 ppm (dry wt.) to 1.4 ppm (Figure 14). Sediment samples from the San Joaquin River at Lander Avenue contained no detectable Se (<0.04 ppm); Salt Slough usually had the highest concentrations (1.1 ppm to 1.4 ppm Se) in sediment. Over the five sampling periods, sediment Se levels at each site were relatively stable in comparison to changes in dissolved Se, particulate Se, and Se in plankton. However, at least one bimonthly sediment sample had a Se concentration substantially different from the other samples taken at the site through the nine month sampling period. These deviations from the typical sediment Se level at a site could not be explained by other Se data we collected and may be related to factors we did not measure. Inconsistency in sample collection or processing also may have affected these results and methodology should be standardized.

Although Se in sediment tended to be highest at the sites with relatively high Se concentrations in other types of samples, and conversely were low when other samples were low, sediment Se concentration was not correlated to dissolved Se

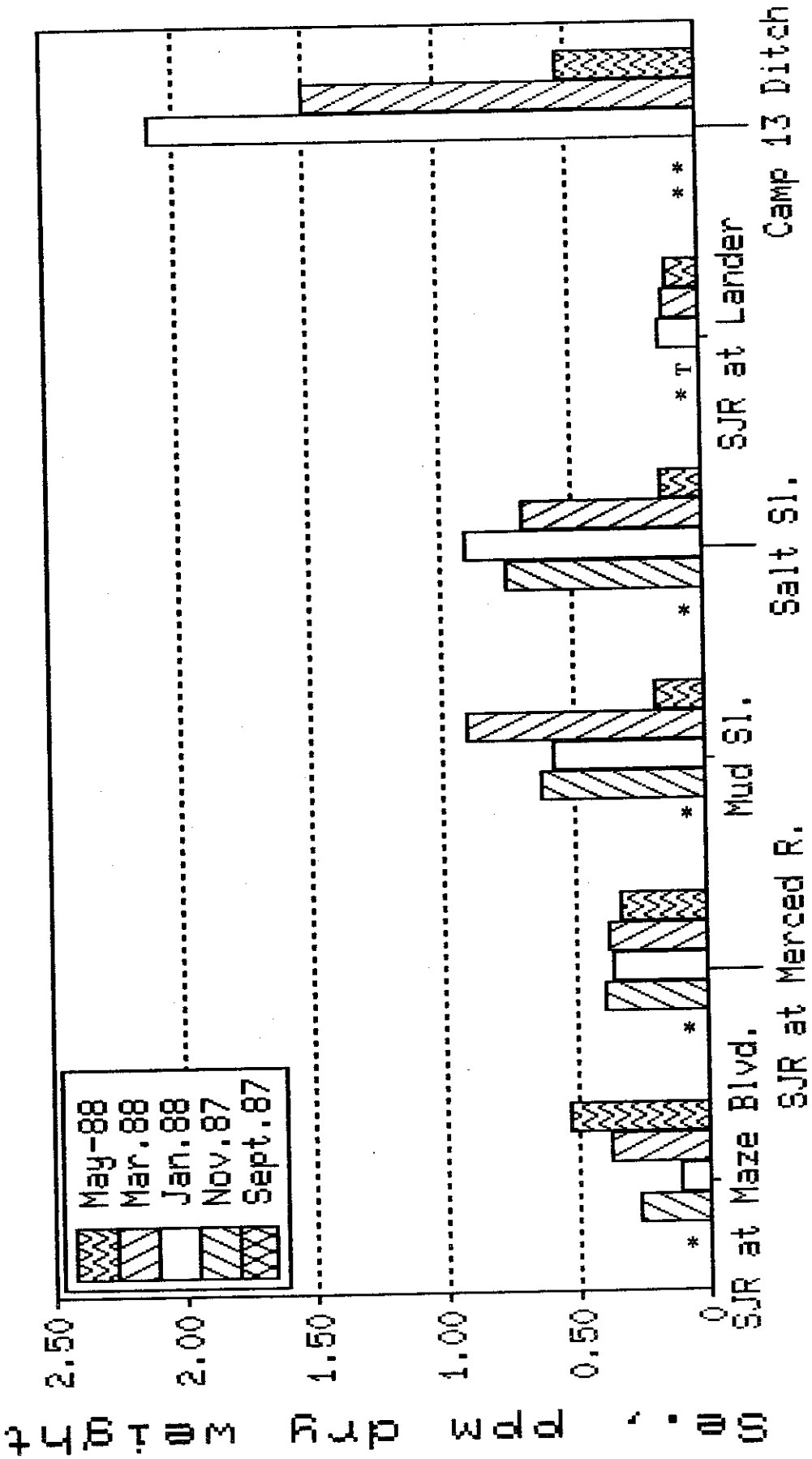


Figure 13. Selenium concentrations (ppm, dry weight) in plankton samples collected at sites in the San Joaquin Valley, 1987-1988. Asterisks, "*", indicate months when no samples were obtained; "T" indicates trace amounts were detected.

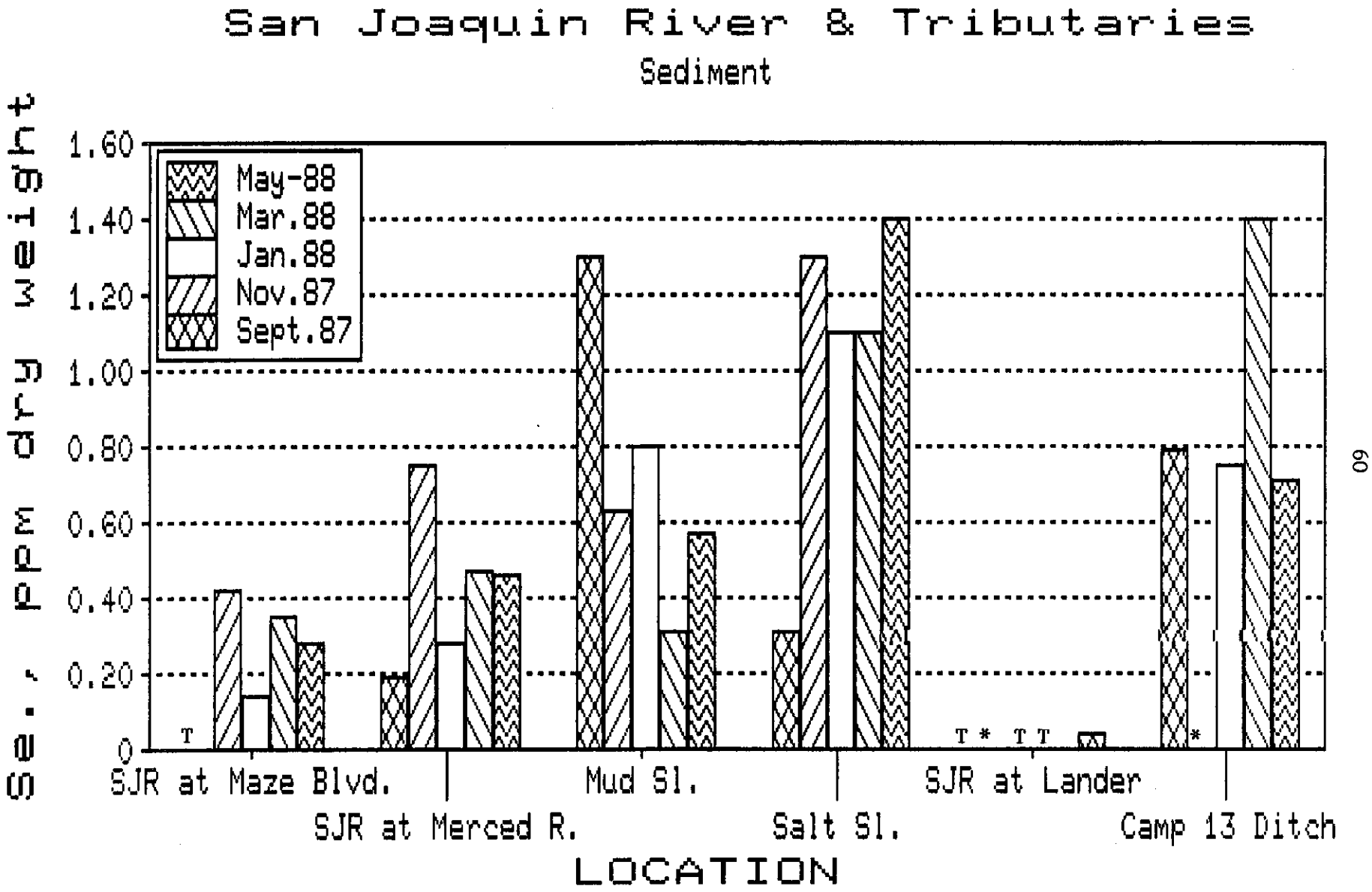


Figure 14. Selenium concentrations (ppm, dry weight) in sediment samples collected at sites in the San Joaquin Valley, 1987-1988. Asterisks, "*", indicate months when no samples were obtained; "T" indicates trace amounts were detected.

concentration measured at the same time. No seasonal pattern consistent among sites was observed.

Sediment Se concentrations in fall 1987 through spring 1988 tended to be higher than concentrations measured in January-February and or April-May 1987 (White et al. 1988), particularly in Salt Slough and in the San Joaquin River at Lander. Only in Mud Slough were Se concentrations in sediment lower in some of the recent samples compared to a year earlier. Although we found no significant correlation between dissolved Se and Se in sediment, the between-year comparisons of sediment Se might be accounted for by the increased use of Salt Slough to carry irrigation drainwater from areas with seleniferous soils and the relative reduction in the use of Mud Slough for that purpose, except during the dewatering of Kesterson Reservoir. Kesterson was dewatered in March and April of 1988 and no clear or consistent pattern of Se concentrations before and after the dewatering is apparent from an examination of Figures 11 to 14. Thus, our limited sampling does not reflect any gross impacts of this process.

Selenium in Catfish

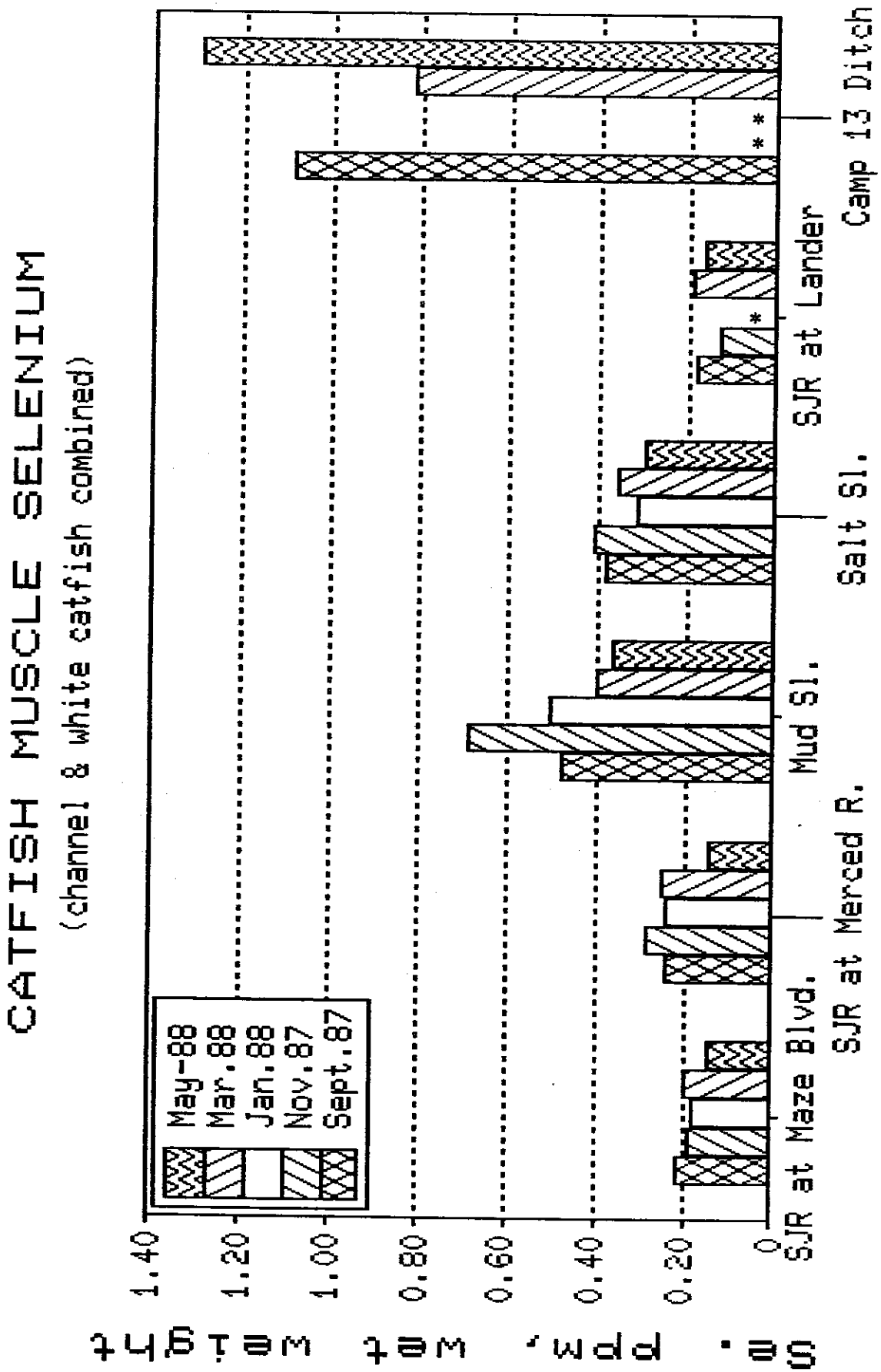


Figure 15. Selenium concentrations (arithmetic mean, ppm wet weight) in muscle tissues of white catfish and channel catfish collected from sites in the San Joaquin Valley, 1987-1988. Asterisks, "*", indicate months when no samples were obtained.

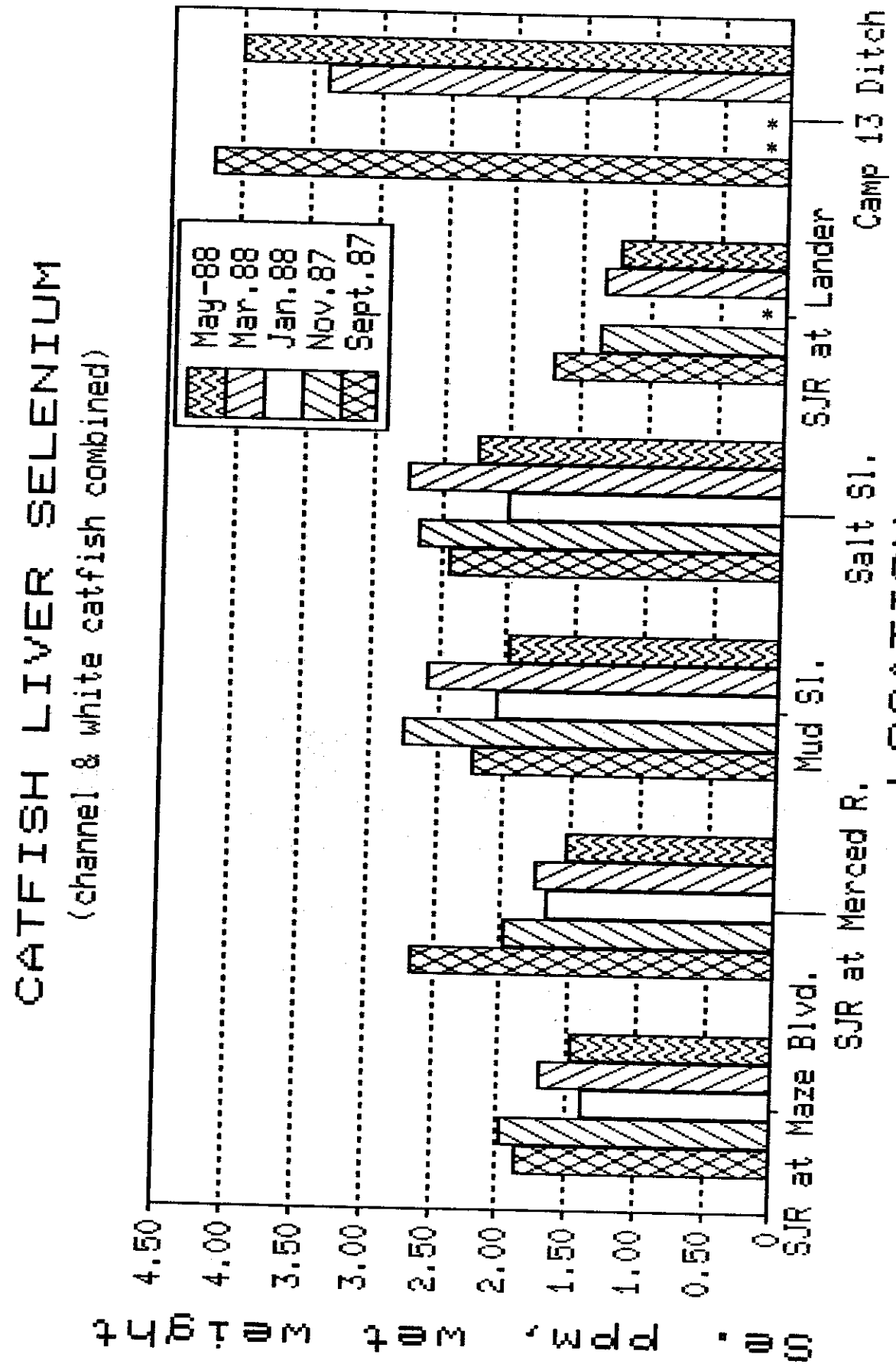


Figure 16. Selenium concentrations (arithmetic mean, ppm wet weight) in liver tissues of white catfish and channel catfish collected from sites in the San Joaquin Valley, 1987-1988. Asterisks, "*", indicate months when no samples were obtained.

ppm) than in catfish from Salt Slough ($\bar{x}$=2.4 ppm), Mud Slough ($\bar{x}$=2.2 ppm), and the San Joaquin River at the Merced River ($\bar{x}$=1.9 ppm), at Maze Blvd. ($\bar{x}$=1.7 ppm), and at Lander Avenue ($\bar{x}$=1.4 ppm). Statistically, the Se level in catfish from each of the latter five sites did not differ from the site with the next lowest concentration, respectively, but did differ from all remaining sites. Thus, Salt Slough was not different from Mud Slough but was greater than the San Joaquin at Merced River and all other sites with lower Se levels in catfish. Comparing only three sampling periods using all five sites, Se levels in catfish liver were higher in September 1987 ($\bar{x}$=2.4 ppm) and March 1988 ($\bar{x}$=2.2 ppm) than in May 1988 ($\bar{x}$=1.8 ppm).

Catfish were obtained during all sampling periods from four of six sites: Salt Slough, Mud Slough, and the San Joaquin River at the Merced River and at Maze Blvd. Analysis of these data indicated Se concentrations in muscle tissue did not differ among catfish muscle collected in September 1987 ($\bar{x}$=0.32 ppm), November ($\bar{x}$=0.35 ppm), January 1988 ($\bar{x}$=0.30 ppm), and March ($\bar{x}$=0.30 ppm). However in May 1988, catfish muscle averaged 0.23 ppm Se, significantly less than during the previous four time periods. Comparisons among the four sites (Figure 15) indicated catfish muscle Se levels were significantly higher in Mud Slough ($\bar{x}$=0.47 ppm) than in Salt Slough ($\bar{x}$=0.35 ppm) and higher in both Mud and Salt sloughs than downstream in the San Joaquin River at the Merced River ($\bar{x}$=0.23 ppm) and at Maze Blvd. ($\bar{x}$=0.18 ppm).

In this second analysis using the four sites where data was available from all five sampling periods, site and season both had a significant effect on Se concentrations in catfish livers. Selenium levels in catfish livers were higher in September ($\bar{x}$=2.27 ppm) and November, 1987 ($\bar{x}$=2.24 ppm) than in January ($\bar{x}$=1.79 ppm) and May, 1988 ($\bar{x}$=1.77 ppm), while March 1988 levels were intermediate ($\bar{x}$=2.15 ppm) and not significantly different from any other month (Figure 16). Catfish from Salt Slough ($\bar{x}$=2.36 ppm) and Mud Slough ($\bar{x}$=2.25 ppm) had similar levels of Se in their livers, but had greater liver Se levels than fish from the San Joaquin River at the Merced River ($\bar{x}$=1.87 ppm) and at Maze Blvd. ($\bar{x}$=1.65 ppm). The concentrations of Se in catfish livers from the two San Joaquin River sites were not significantly different. These four area comparisons over all five time periods did not differ substantially from the six-area comparisons using only three time periods that were discussed in the previous two paragraphs.

Summary

The comparison among sample locations of the Se concentrations measured in all types of samples provide a relatively clear picture of the overall behavior of Se in the river system. Mud Slough and Salt Slough have carried Se-enriched drainwater during recent years and comprise the major input to the river system. Biotic and abiotic components in these sloughs clearly reflect fluctuating exposure to elevated dissolved Se levels.

In the San Joaquin River upstream from the influence of tributary flow from Mud and Salt Sloughs, all media contained the lowest Se concentrations measured in the river system. Moving downstream in the San Joaquin River below the Merced River confluence, dissolved Se and Se in fish, plankton and sediment were clearly influenced by Se input from drainwater in the sloughs, but were generally not as high as levels in the sloughs. Further downstream at Maze Blvd., Se concentrations

nets to have empty stomachs by the time they were removed from the net. Attempts to collect benthic invertebrates that probably constitute part of the omnivorous catfish diet were not successful. Further work in this area may be desirable.

Second, fish sampling in the San Joaquin River has focused on white and channel catfish which may not be susceptible to the accumulation of Se. Se concentrations ranged from 1.5 ppm to 2.5 ppm (wet wt.) (8.1 ppm to 11.0 ppm dry wt.) in muscle tissue from seven green sunfish from Camp 13 Ditch, where catfish composites contained 0.66 ppm to 1.5 ppm (wet wt.), suggesting that centrarchid species of fish may be more efficient at bioaccumulation and potentially susceptible to the deleterious effects of Se. Future sampling should consider other species besides catfish, and bass and sunfish are probably good candidates.

Third, no evaluation has been made of the site-specific reproductive toxicity to fish of the levels of Se we measured in various components of the aquatic environment. Such an investigation would be very complex and is beyond the scope of the Se Verification Study.

AGRICULTURAL EVAPORATION PONDS

Subsurface agricultural drainage is ponded for storage and evaporation at an increasing number of sites in the San Joaquin Valley. This drainwater contains a variety of potentially toxic constituents, including selenium. In this arid region which formerly supported large populations of wintering waterfowl in naturally-occurring seasonal wetlands, evaporation basins attract numerous species of waterfowl and shorebirds.

Development of a strategy for regulating evaporation basins and protecting waterfowl and shorebirds from contaminant exposure at these sites requires data on the relationship between waterborne concentrations of contaminants and concentrations in bird tissues.

Human health may be jeopardized by consumption of contaminated birds. Based on results from our sampling to date, the Department of Health Services has advised limited consumption of coots from agricultural drainage evaporation ponds.

Initial sampling for selenium in biota at evaporation ponds, including Verification Study efforts in 1986, has been followed by various investigations of water quality, community structure and contaminant levels of aquatic invertebrates, bird use patterns and food habits, bird condition, and reproductive success of birds breeding at these sites. The most general of these studies have been conducted at a large number of pond systems while intensive studies (e.g., bird reproduction) have involved only a few systems. Participants include several research units of the U. S. Fish and Wildlife Service, Department of Water Resources, Central Valley Regional Water Quality Control Board (Fresno), University of California (Davis), and California State University (Fresno).

Each study of evaporation ponds was designed with a specific purpose. Despite some degree of coordination, this combination of investigative efforts has not generated a consolidated data set covering all ecosystem components. In order to investigate the interrelationships of selenium levels among the components in evaporation pond ecosystems, we collected and measured selenium in samples of filtered water, suspended particulates, plankton, sediment, invertebrates, and ruddy duck muscle and liver tissues. The sample collections were coordinated with USFWS wintering duck condition and feeding studies, and with DWR monitoring of contaminant levels in water and invertebrates.

Ruddy ducks were selected for food habits and condition studies by the USFWS. Ruddy ducks are a good species to monitor at evaporation ponds because they are found at most pond sites and because they tend to spend all their time on-site and do not disperse to feed or loaf elsewhere.

Primary breeding areas for ruddy ducks are the prairie potholes region and the intermountain west (Bellrose 1978).

Approximately 47% of the continental population winters in California with most concentrating in the San Francisco Bay area. Past studies have shown ruddies to be largely vegetarians, however, preliminary food habits information from the evaporation ponds indicates their diet there consists largely of invertebrates (Barnum, pers. comm.).

The four study sites chosen for investigation are located in the southwest San Joaquin Valley near the intersection of Kings, Kern and Tulare Counties (Figure 17, Appendix A). The Meyers Ranch evaporation ponds are 2 km east of Stratford and the Westlake 3 ponds are 7 km southeast of Kettleman City, both in Kings Co. The Pryse evaporation ponds are 3 km north of Alpaugh, Tulare Co., and the Westfarmers ponds are southeast of the intersection of Twisselman Rd. and Interstate Highway 5 in Kern Co.

Selenium levels in ruddy ducks were generally highest at Westfarmers and Pryse, intermediate at Westlake and lowest at Meyers (Table 14). Mean selenium levels in ruddy duck breast muscle tissue from Westfarmers ponds ($\bar{x}$=22 ppm, dry weight) were not significantly different from those from Pryse evaporation ponds ($\bar{x}$=16 ppm). Breast muscle tissues from Pryse were not significantly different from those from Westlake ponds ($\bar{x}$=9.6 ppm), and muscle selenium levels from Westlake were not significantly different from those of Meyers evaporation ponds ($\bar{x}$=4.2 ppm). Muscle Se levels in ruddy ducks at Westfarmers were significantly higher than those at Westlake and Meyers, and Se levels in ducks at Pryse were also significantly higher than those at Meyers.

Mean liver selenium levels were not significantly different among ruddy ducks from Pryse, Westfarmers and Westlake evaporation ponds. Liver selenium levels in ducks from Meyers were significantly lower than in those from the other three sites.

The four pond complexes varied in average selenium water concentration. In descending order of concentration they were Westfarmers, Pryse, Westlake #3 and Meyers.

Concentrations of selenium increased with each trophic level (Table 14, Figure 18). Concentrations were lowest in filtered water and increased sequentially in sediments, filterable particulates, plankton, invertebrates, ruddy duck tissue. While some sites showed slight deviations from this pattern, a Spearman rank correlation test showed a significant correlation between increasing selenium concentrations and increasing trophic levels.

Bioaccumulation was greatest at the lowest trophic level. Selenium levels increased 13 to 6000 times from levels in the water to levels in filterable particulates (Figure 18). Biomagnification factors were less than ten for each trophic step above the particulate level.

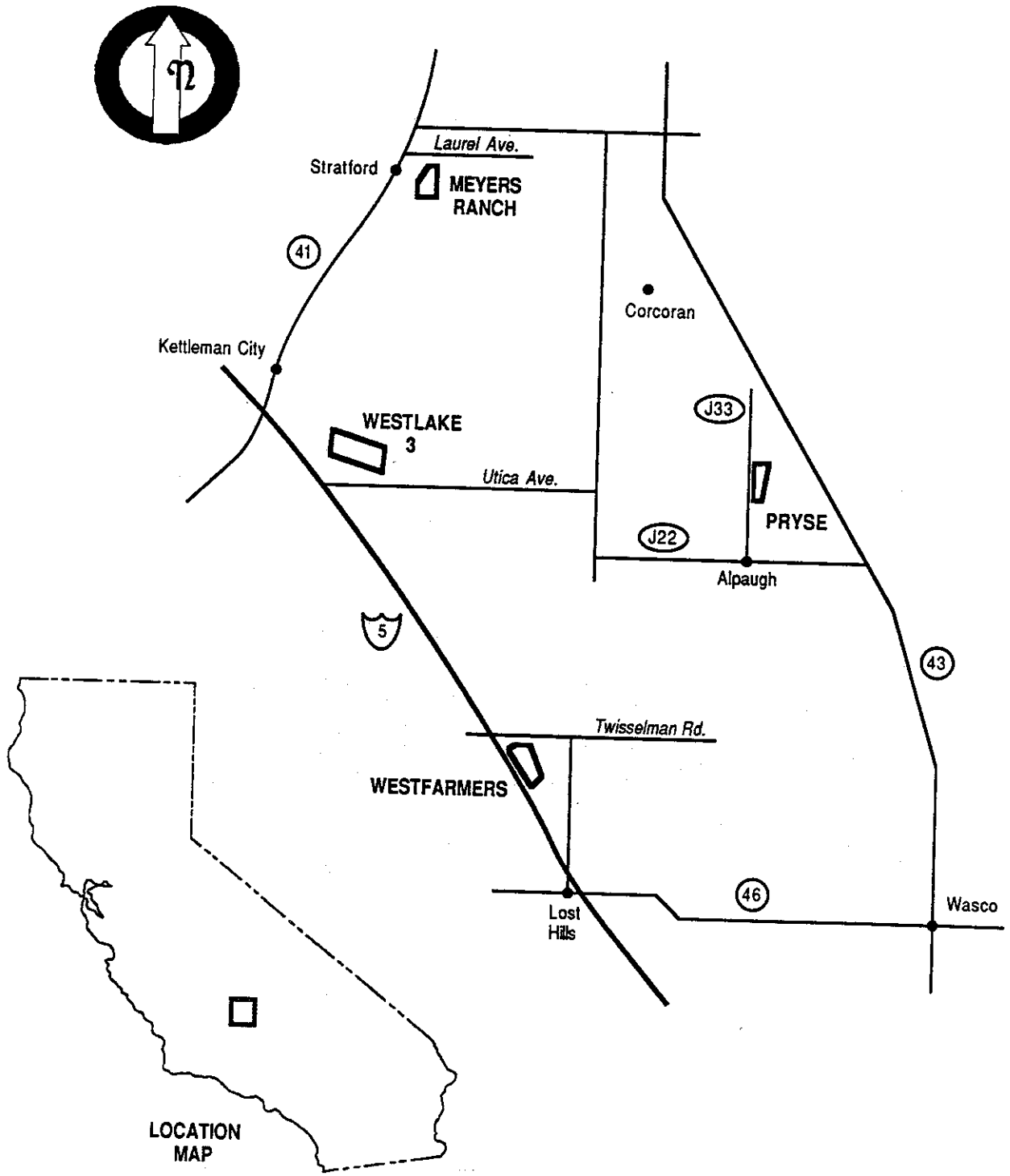


FIGURE 17. Selenium Verification Study - Agricultural Drainwater Evaporation Pond Sampling Sites, 1987-88

Table 14. Selenium concentrations in filtered water, sediments, suspended particulates, plankton, and ruddy duck tissues from Southern San Joaquin Valley agricultural drainage water evaporation ponds.

Site[1/]	Water[2/]	Sediment[3/]	Particulates[3/]	Plankton[3/]	Invertebrates[3/]	Ruddy Ducks[3/5/] Muscle	Liver
WFRMR	0.160	1.9	24.	27	46:		
WFRMR	0.460	.91	6.2	9.0	16.	22	45
WFRMR	0.100	1.1	9.7	7.5	11.[4/]		
PRYSE	0.008	1.7	4.8	11	9.8	16	59
WLAKE	0.003	.25	3.0	4.7	3.7[4/]	9.3	31
WLAKE	0.003	.41	1.0	7.2	5.7		
WLAKE	0.004	.15	.49	1.1			
MEYER	<0.001	.41	1.8	<1.3	1.4[4/]	4.2	12
MEYER	<0.001	.84	1.1	<1.6	2.0[4/]		

1/ See Table 3 for key to location codes
2/ ppm as mg Se/Kg H_2O
3/ ppm, dry weight
4/ Analyses by DWR, Bryte Lab
5/ Mean values, N = 10 for each site

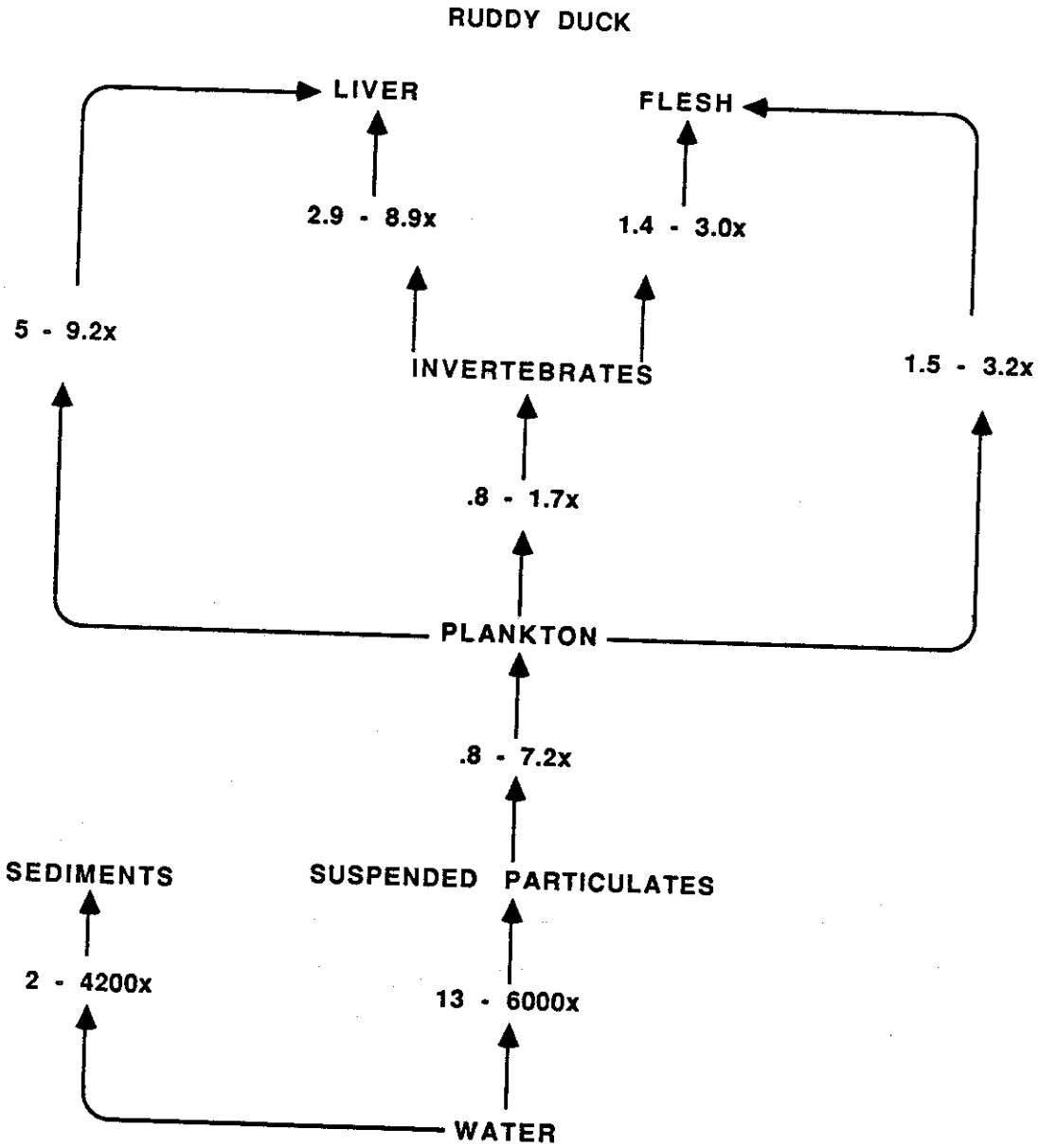


FIGURE 18. Bioaccumulation factors between trophic levels in the food chain of ruddy ducks from south San Joaquin valley agricultural drainage water evaporation ponds. Factors were derived from mean dry weight concentrations of samples shown in Table 14.

Waterborne levels of selenium in Westfarmers pond 3A were higher in 1988 (460 ppb) than when sampled in 1986 (70 and 109 ppb, White et al., 1987). Selenium levels in corixids were slightly higher in 1988 (15 ppm, dry wt.) than in 1986 (13 ppm, dry wt.). The selenium levels found in invertebrates at Westfarmers 3A were less than the levels linked to bird deformities at Kesterson NWR (Ohlendorf et al. 1986a; $\bar{x}$>22.1 ppm, dry wt.); however, laboratory studies showed increased embryonic deformities in mallards fed a diet containing only 10 ppm selenomethionine (Heinz et al. 1987). Invertebrates from both Westfarmers and Pryse ponds had selenium levels approximating or exceeding 10 ppm, dry weight.

The levels of selenium found in ruddy duck livers from Westfarmers (45 ppm, dry wt.) and Pryse (59 ppm, dry wt.) were higher than the levels that were associated with embryonic deformities in coots ($\bar{x}$ = 37 ppm, dry wt.) and ducks ($\bar{x}$ = 29 ppm, dry wt.) at Kesterson NWR (Ohlendorf et al. 1986). However, data for different species may not be comparable, so levels deleterious to coots may have no effect on ruddy ducks. The level of which selenium in tissue would adversely impact ruddy ducks has not been quantitatively determined.

TRACE ELEMENTS ANALYSES

Two-hundred eighty-one selected samples of bird and fish livers, invertebrates and water were sent to the Calfornia Veterinary Diagnostic Laboratory System's Toxicology Laboratory (VDTL) at UC Davis for analysis of twenty trace and toxic elements. All samples were from 1987-88 collections with the exception that surf scoter samples were from both 1986-87 and 1987-88, and coots were from 1986-87 only. The twenty elements analysed were aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, silver, vanadium, zinc and selenium. The data that resulted is most useful as baseline information; however, for eight elements (arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc) enough information exists to warrant a brief discussion of toxicological significance.

Arsenic

Background arsenic concentrations are generally less than 1.0 ppm fresh weight (FW) in terrestrial flora and fauna (Eisler 1988). Shorebirds wintering in Texas contained an average of 0.3 ppm fresh weight (FW) arsenic in livers with a maximum of 1.5 ppm FW (White et al. 1980). These were considered to be at background levels. Arsenic levels in liver tissue above 2.0 ppm FW are considered elevated for birds with liver tissue concentrations greater than 10 ppm FW indicative of arsenic poisoning (Eisler 1988).

Reported background concentrations of arsenic in livers of freshwater fish were less than 1.0 ppm dry weight (DW) (Eisler 1988). Sensitive aquatic species were damaged at water concentrations of 19 to 48 ppb; the EPA criterion for the protection of fresh water aquatic life is a four-day average of 190 ppb, or a one-hour average of 360 ppb, both not to occur more than once in three years; and the EPA drinking water criterion is 50 ppb arsenic (Eisler 1988). Marine species have higher background levels of arsenic than freshwater or terrestrial organisms, and the EPA criterion for the protection of salt water aquatic life is a four-day average of 36 ppb, or a one-hour average of 69 ppb, both not to occur more than once in three years.

Only two bird livers exceeded 2.0 ppm FW. One was from a surf scoter collected on San Pablo Bay (15.7 ppm) and the other was from a ruddy duck collected from the Pryse evaporation ponds (2.9 ppm). Ruddy ducks from Pryse showed elevated levels compared to other locations with 6 of 10 samples having levels above 1.0 ppm FW. No freshwater fish livers exceeded 1.0 ppm FW. White sturgeon livers were all over 1.0 ppm FW but marine species normally have higher background levels of arsenic. Highest arsenic concentrations in water were from agricultural evaporation ponds. Six of nine samples exceeded 20 ppb, and two of these, Westlake cell 6 and Pryse cell 1, had levels of 174 ppb and 490 ppb respectively.

Cadmium

Vertebrate liver levels that exceed 10 ppm FW or whole body samples that exceed 2.0 ppm FW should be viewed as evidence of cadmium contamination. Water cadmium concentrations of 0.8 to 9.9 ppb were lethal to several species of aquatic invertebrates and teleosts (Eisler 1985a). Eisler (1985a) considered water levels in excess of 3.0 ppb cadmium to be potentially hazardous to aquatic biota.

None of the bird or fish livers in our study exceeded 10 ppm FW cadmium. Highest levels were from two surf scoters, one from Suisun Bay (8.8 ppm FW) and the other from San Pablo Bay (6.4 ppm). Only one water sample attained 3 ppb cadmium. This sample was from Humboldt Bay but a second sample taken at the same location later that day was below the detection limit of 2 ppb. It may be presumptuous to make inferences when working so close to the detection limit.

Chromium

Chromium levels in organs and tissues of fish and wildlife that exceed 4.0 ppm DW should be viewed as presumptive evidence of chromium contamination. The California drinking water standard for chromium is 50 ppb although sensitive species of freshwater aquatic organisms showed adverse effects at 10.0 ppb Cr^{+6} and 30 ppb Cr^{+3} (Eisler 1986).

All vertebrate tissues that we sampled had levels of chromium well below 1.0 ppm DW. Samples of invertebrates from Humboldt, Suisun and San Pablo bays and from Westfarmers evaporation ponds frequently exceeded 4.0 ppm DW, but no evidence of elevated levels were seen higher in the food chain. Only two water samples exceeded 10 ppb chromium; both samples were from Camp 13 Ditch. Catfish liver levels from Camp 13 Ditch had slightly higher chromium levels than other samples from the San Joaquin Valley, but all were still below 0.2 ppm DW.

Copper

Copper levels in livers of diving ducks were considered to be elevated at levels above 100 ppm DW by Ohlendorf et al. (1986c); however, detrimental effects from these levels have not been demonstrated. The EPA recommended water quality criterion from protection of freshwater aquatic life is a 24-hour average not to exceed 5.6 ppb.

Six of 14 (43%) coots collected from Suisun Bay had liver copper levels above 100 ppm DW but only 5 of 87 (6%) surf scoters from the various San Francisco Bay/Estuary stations had levels above 100 ppm DW. Higher levels of copper in certain ducks have been associated with an herbivorous diet, which is the probable reason for the higher levels in coots. Two of 10 ruddy ducks from Westfarmers, 7 of 10 from Westlake, 7 of 10 from Meyers and 9 of 10 from Pryse evaporation ponds had liver levels that exceeded 100 ppm DW.

Nine of 10 white sturgeon collected in the winter of 1987-88 had copper levels above 100 ppm DW. The only invertebrate samples that exceeded 100 ppm DW were two samples of bivalves from Humboldt Bay at 275 ppm and 245 ppm DW. Water samples that exceed 6.0 ppb came from Westfarmers evaporation ponds (8, 12 and 9 ppb), Westlake evaporation ponds (two at 8 ppb), San Pablo Bay (two at 6 ppb) and one sample of 6 ppb from the San Joaquin River at Lander Avenue. The detection limit for copper at VDTL was 5 ppb, so the significance of the samples at 6 ppb may be questionable.

Lead

Liver lead concentrations of 6-8 ppm FW or higher are suggestive of lead poisoning in waterfowl (Friend 1987), although normal background levels are generally below 1.5 ppm FW (Ohlendorf et al. 1986c). The current drinking water standard for lead is 50 ppb (Linck 1981), although young striped bass showed significant mortality at concentrations as low as 1.2 ppb in soft water (Pawlawski et al. 1985).

Only one bird had liver lead concentrations greater than 2.0 ppm FW and that was a surf scoter from San Pablo Bay with a concentration of 575 ppm FW. It is not known if this was the result of ingesting lead or from unknown contamination of the sample. Other than this scoter, only two birds had levels above 1.0 ppm FW; both of these were Ruddy ducks, one from Westlake evaporation ponds (1.96 ppm FW) and the other from Meyers evaporation ponds (1.18 ppm FW). One composite sample of catfish livers from the San Joaquin River at Lander Avenue contained 2.07 ppm FW lead. The reason for the high levels in this sample is unknown since others from the same site were all below 0.25 ppm FW.

Invertebrate samples from Suisun, San Pablo and Humboldt Bays commonly exceeded 1.0 ppm FW although these levels were not reflected higher in the food chain. None of the water samples exceeded 50 ppb although levels at or above 10 ppb were detected from one sample from Westfarmers (16 ppb) and one sample from Westlake (10 ppb) evaporation ponds.

Mercury

Concentrations greater than 1.1 ppm FW in organisms should be considered as presumptive evidence of an environmental mercury problem (Eisler 1987). Levels in freshwater of 0.03 to 0.1 ppb have been shown to adversely affect selected aquatic species. The proposed EPA water quality criterion for the protection of freshwater aquatic life is 0.012 ppb for a four day average (Eisler 1987), well below the detection limit of VDTL (0.2 ppb).

Scoters collected from San Pablo and Suisun Bays in fall 1987 all had liver mercury levels below 0.4 ppm FW. Scoters collected from the same areas in late February 1988 after wintering on San Francisco Bay/Estuary all had liver mercury

levels greater than 1.5 ppm FW. This would seem to indicate that diving ducks are accumulating mercury as they winter on San Francisco Bay/Estuary.

Ruddy ducks from evaporation ponds reflected varying degrees of mercury contamination. Two of 10 ruddies from Westfarmers, 7 of 10 from Westlake, none of the ruddies from Meyer and only one of 10 ruddies from Pryse showed levels above 1.0 ppm FW. Only one fish liver sample showed mercury levels above 1.1 ppm FW. This was from a white sturgeon collected in San Pablo Bay. However, the Department of Health Services currently has a health advisory for striped bass consumption by anglers, based on mercury contamination found in other more extensive sampling. Highest mercury levels in invertebrates were in bivalves from Humboldt Bay (0.2 ppm FW) and from Pryse evaporation ponds (0.15 and 0.16 ppm FW). Water samples that exceeded or equalled the detection limit (0.2 ppb) were from Pryse (0.7 ppb), Westlake (0.2 ppb) and San Pablo Bay near the Petaluma River mouth (0.4 ppb).

Nickel

Recorded nickel residues in livers of wild birds were generally below 1.0 ppm FW (Ohlendorf et al. 1986c). Acute toxicity to young striped bass occurred at concentrations of 3900 ppb in soft water (Pawlawski et al. 1985). The EPA criterion for the protection of freshwater aquatic life is a 24-hour average of 56, 96, or a 160 ppb in water or a 1100, 1800, or 3100 ppb spike (one time sample) with a hardness of 50, 100, or 200 mg/l, respectively (Linck 1981). The EPA criterion for the protection of salt water aquatic life is 7.1 ppb as a 24-hour average, or a spike (one time) sample of 140 ppb.

Only six birds had liver nickel levels greater than 1.0 ppm FW and four of these were scoters collected from South San Francisco Bay. The two other scoters were collected from Central San Francisco Bay (1.5 ppm) and from Suisun Bay (1.7 ppm).

Catfish collected in the fall of 1987 from the San Joaquin Valley frequently had liver levels greater than 1.0 ppm FW. Thirty of 31 catfish liver samples collected from the same San Joaquin Valley sites in January and March of 1988 had levels below the detection limit of 0.2 ppm FW. The only sample that was above the detection limit was at 0.4 ppm.

Bivalves from San Francisco Bay/Estuary and from Humboldt Bay commonly were above 1.0 ppm FW, but these levels were not reflected higher in the food chain. None of the water samples exceeded 50 ppb.

Zinc

Background levels of zinc in bird livers are generally less than 150 ppm DW (Ohlendorf et al. 1986c, Di Giulio and Scanlon 1984). Acute toxicity to juvenile rainbow trout occurred at

zinc levels of 93 ppb and to larval striped bass at 120 ppb in soft water (Pawlawski et al. 1985). The EPA water quality criteria for the protection of freshwater aquatic life is 47 ppb.

Seventeen of 29 coots (59%) from Suisun Bay had liver zinc levels greater than 150 ppm DW, yet only eight of 87 (9%) surf scoters from San Francisco Bay/Estuary had levels above 150 ppm DW. This was possibly the result of the coot's herbivorous diet. Higher concentrations of zinc have been associated with a herbivorous diet in other waterfowl species (Ohlendorf et al. 1986c). Westfarmers, Pryse and Meyers evaporation ponds each had one ruddy duck with liver levels above 150 ppm DW.

Some Corbicula samples from Suisun Bay and two samples of Macoma nasuta from Humboldt Bay exceeded 150 ppm DW. Bay. None of the water samples analyzed had water concentrations above 10 ppb.

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APPENDICES

APPENDIX A

Antioch - 38°03'N, 121°42'W. The San Joaquin RIver near Schad Landing, approximately 7 km upstream of the Antioch Bridge, Contra Costa County.

Camp 13 - 38°56'N, 120°42'W. The Camp 13 Ditch, just downstream from its intersection with the C.C.I.D. Main Canal, approximately 17 km south of Los Banos, Merced County.

Clarksburg - 38°26'N, 121°31'W. Sacramento River adjacent to Clarksburg, Yolo County.

Humboldt Bay - 40°43'N, 124°14'W. Humboldt Bay, Humboldt County.

Meyers Ranch Evaporation Ponds - 36°19'N, 119°51°W. Evaporation ponds located south of Laurel Ave, approximately 2 km east of Stratford, Kings County.

Mud Slough - 37°16'N, 12°55'W. Mud Slough on Kesterson National Wildlife Refuge, approximately 200 m. north of the end of the San Luis Drain, Merced County.

Pryse Evaporation Ponds - 35°51'N, 119°32°W. Evaporation ponds east of county road J33, approximately 3 km north of Alpaugh, Tulare County.

Salt Slough - 37°15'N, 120°51'W. Salt Slough upstream from the Lander Avenue (Highway 165) crossing, Merced County.

San Joaquin River at Lander Road - 37°18'N, 120°50'W. San Joaquin River downstream from the Lander Avenue (Highway 165) crossing, Merced County.

San Joaquin River at Merced River - 37°21'N, 120°58'W. San Joaquin River just downstream from its confluence with the Merced River, Merced County.

San Pablo Bay - 38o03'N, 122o23'W. San Pablo Bay north of the Richmond-San Rafael Bridge and west of the Carquinez Bridge.

Suisun Bay - 38°04'N, 122°03'W. Suisun Bay between the Carquinez Bridge and Antioch, including Grizzly Bay.

San Joaquin River at Maze Blvd. - 37°36'N, 121°10'W. San Joaquin River south of the Highway 132 (Maze Blvd.) crossing, 10km east of Vernalis, Stanislaus County.

Westfarmers Evaporation Ponds - 35°44'N, 119°44'W. Evaporation ponds located southeast of the intersection of Twisselman Road and Interstate 5, Kern County.

Westlake 3 Evaporation Ponds - 35°56'N, 119°50'W. Evaporation ponds north of Utica Ave., approximately 7 km southeast of Kettleman City, Kings County.

APPENDIX B. Sample Preparation.

Sample Container Preparation

Glass milk dilution bottles (160 mL) with Teflon-lined screw lids serve as sample containers. Bottles and lids are washed with warm water and soap (Haemo-sol) manually or by dishwasher. Care must be taken using the dishwasher because soap residue may adhere to the inner surface of the bottles and/or lids. Usually a second rinse will correct this problem. After thoroughly rinsing both bottle and lid with tap water, rinse the inner surfaces as follows:

1) 25 mL of 1.0 M nitric acid (analytical reagent grade);
2) 25 mL of Type I reagent grade water (ASTM 1986);
3) 25 mL of 2-propanol (analytical reagent grade).

To ensure all surfaces are exposed to solvents, rotate bottles when pouring out solvents. Allow 15 minutes for bottles to air-dry before using.

If linear polyethylene (LPE) bottles are to be used, fill with 1.0 M nitric acid and allow to soak for at least 24 hours and rinse with Type I water.

Clean Room Preparation for Dissection and Homogenization

Before entering the clean room, set the fan to the highest speed. This will create a positive pressure of filtered air to prevent contaminants from entering the room. Hands must be washed thoroughly before handling any samples or equipment used in dissection. Allow deionized water to run 5 to 10 minutes to purge the pipes. All counter tops and glass surfaces must be wiped with Kimwipes and Type III general laboratory water (ASTM 1986). Finally, the glass surfaces used for dissection must be covered with aluminum foil with the dull face of the foil exposed. Use the following list for equipment check:

aluminum foil
chromium coated nickel-silver scalpel handles
carbon steel scalpel
Teflon forceps
large and small "v" tissue forceps
pliers, cutting
glass milk dilution bottles (160 mL) with Teflon lined lids
1.0 M nitric acid (analytical reagent grade)
2-propanol (analytical reagent grade)
vernier caliper
deionized water (Type I and Type III)

APPENDIX B. Sample Preparation. (Continued)

Dissection Tool Preparation

All dissecting tools must be chemically cleaned before touching the sample(s). All tools must be recleaned and blades changed after each composite or individual sample.

Wash tools (except blades) using warm soapy water and toothbrush. Attach clean blades to scalpels, then briefly rinse all tools in 1.0 M nitric acid, Type I water, and 2-propanol. Place tool handles on a foil covered box so blades are suspended over the edge on the box.

Periodic washing of the solvent bottles and changing of the solvents will be necessary to reduce the possibility of contaminating subsequent samples. Solvent bottles must be washed at least once a week and solvents changed about every tenth sample or after each day.

Sample portions to be used for analysis may only be touched by dissecting tools and the inside of the bottle. Contaminated equipment must be recleaned. Minimize solvent contact with skin. Wash skin after contact with solvents.

Dissection Procedures

General

Remove frozen samples from freezer and thaw just enough to allow dissection. Packages may be thawed overnight in the refrigerator, or to accelerate thawing the package is opened and the exposed samples are placed under running Type III deionized water. If whole body samples are to be used, Type I water is used to thaw samples (see Whole Body Samples). Record length (to nearest mm) and weight (to nearest 0.1 g) for each individual. For example, fork length is used for fish and the length of beak to tail is used for birds. Samples to be dissected are then placed on aluminum foil to air dry. If there is excess mucous, a toothbrush and Type II water may be used to scrub the fish (for non-whole body samples only). Whole body samples can be cleaned by holding the individual(s) with chemically cleaned Teflon forceps under a stream of Type I water.

All dissected portions of the sample are placed in a chemically cleaned milk dilution bottle and labeled with the sample number. The bottle weight and the weight of the bottle plus the dissected material must be recorded on a dissection data sheet. The sample is then ready for homogenization.

APAPENDIX B. (Continued)

Fish Flesh

Dissect the smallest fish of a composite first. The weight of this tissue sample will determine the weight of the tissue core to be taken from other fish in the composite; these weights should be equal. The weight contribution of each fish in the composite is recorded. Ideally, a total of 50 g of flesh is needed for analysis. Blade changes or instrument washing is not necessary when cutting fish from same composite unless instruments become contaminated.

Make a U-shaped incision in the skin using a clean scalpel (Figure 1). The curved portion of the incision is just posterior of the operculum. The legs of the U-shaped incision run the length of the body just ventral to the dorsal fin and just ventral of the lateral line and should be just deep enough to cut only the skin. Grasp the skin near the operculum with the tissue forceps and pull the skin caudally, exposing the flesh. If the fish is unusually large or the skin unusually hard to peel back, the pliers used to remove the scalpel blades can be used to remove the skin. Naturally, the pliers must be chemically cleaned before this use.

Make an oval incision with a second scalpel in the flesh inside the "U" formed by the previous incision. This new incision should be well inside the area touched by either the incision scalpel or the forceps as described in previous steps. Ideally, take the inner core 1 cm inside the anterior end of the incision scalpel cut and 5 mm inside the remaining portion of the "U". Small fish do not allow the luxury of these buffering zones and may require that flesh from both sides of fish be taken.

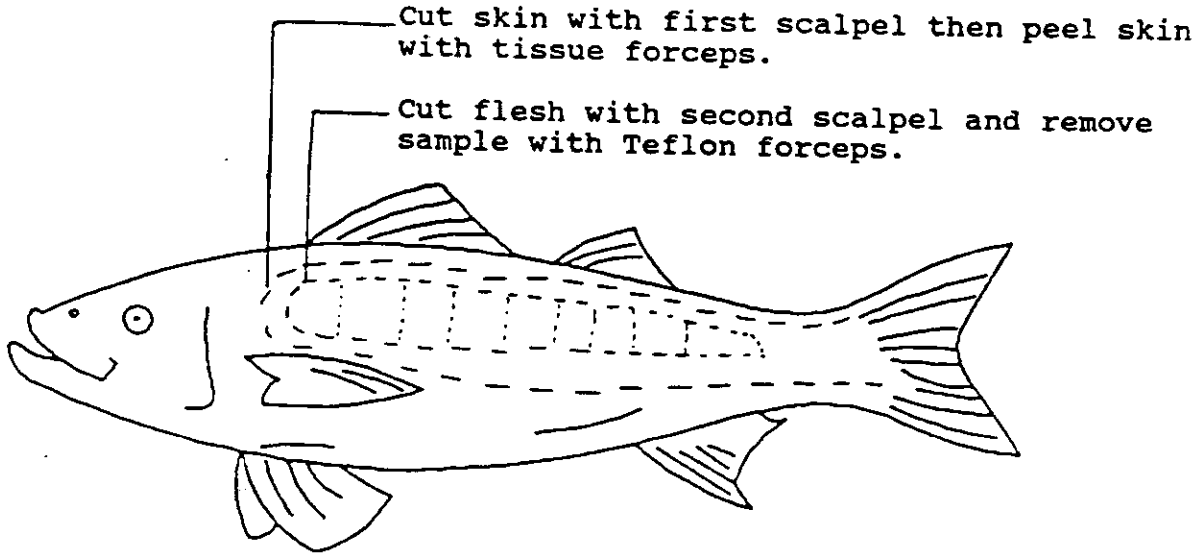

FIGURE 1. Diagram of fish dissection.

APPENDIX B. Sample Preparation. (Continued)

Care must be taken to minimize the contact of flesh samples from small fish with the incision cut. Use clean Teflon forceps to hold the core while the coring scalpel is used to free it from the skeleton. Subsamples from the core should represent the entire length of the fish; these should be cut in small pieces (5 to 10 g) and rinsed with Type I water before being placed in the bottle. Weigh the empty bottle and the flesh from each individual for composite samples. Any sample pieces dropped must be thrown away. Any irregularities like tumors, parasites, or wounds should be noted on the data sheet.

Bird Flesh

After the flesh has been fluoroscoped to locate lead or steel shot, the portions not contaminated by pellets are ready for dissection. Use only the portions of breast that have not been exposed to the air (inner core) to make up the sample. Using a scalpel, dissect strips of flesh from the length of the breast for a total weight of approximately 50 g. These strips are then placed in a sample bottle. Use chemically cleaned instruments for dissection of each new sample to avoid cross contamination.

Liver

Livers of birds and some species of fish are removed for analysis. This is achieved by opening the thoracic and abdominal area using the incision scalpel and removing the liver using another scalpel and Teflon forceps. The liver is then rinsed with Type I water, and placed in the sample bottle. When preparing composite liver samples, each individual liver is weighed and values are recorded on the dissection sheet.

Whole Body Samples

If whole body samples are to be prepared, a slightly different technique is required. Only chemically clean Teflon instruments can touch whole body samples. Samples are removed from

APPENDIX B. Sample Preparation. (Continued)

measured at its longest point before it is rinsed with Type I water. The outer shell may be touched by hand but the inner parts may not. The shell is then broken open by hand and tissue inside the shell is removed with the use of Teflon forceps and a scalpel. Dissected portions of the shellfish are placed in a sample bottle and measurements are recorded on the sample dissection sheet.

Homogenization Procedures

Samples are first thawed. A measured amount of Type I water may be added to flesh and whole body samples to help facilitate homogenization. Water is not added to liver samples. Equipment needed in the homogenization procedure include:

Polytron with titanium shaft and Teflon bearing
Safety goggles and ear protectors
3 1000 mL beakers
2 400 mL beakers
1 160 mL milk dilution bottle
Teflon wash bottle
Teflon policemen
stainless steel forceps

The two 400 mL beakers and the 160 mL milk dilution bottle

APPENDIX B. Sample Preparation. (Continued)

Homogenization of flesh and liver samples with a Polytron can be dangerous. Ear protection and safety goggles must be used at all times when operating the polytron. Place sample bottles in a LPE protective sleeve to protect operator from glass if the bottle shatters. Keep a firm grip on the beaker or bottle. High speeds should not be used because friction will cause the samples to burn; use only the minimal amount of power needed to homogenize the sample. Inspect the machine before and after each day's work for any loose play in the generator. The bushing in the shaft will have to be changed when the play becomes excessive and the generator sounds noticeably louder during operation.

APPENDIX C. Analysis

General

All tissue, water, sediment, filter residue, and plankton samples are analyzed for selenium at WPCL by hydride generation atomic absorption spectrophotometry (HGAA).

WPCL HGAA Selenium Analysis Procedure for Tissue

Dry Ashing Procedure[1/]

1. In a 100 mL Pyrex beaker with watch glass cover, place approximately 0.25 g to 0.50 g of wet tissue or 0.20 g of lyophilized tissue wetted with methanol.
2. Add 8 mL of reagent grade 50% $Mg(NO_3)_2 \cdot 6H_2O$, 50% H_2O (w/w).
3. Add 100 to 300 uL Dow Corning DB150A antifoam emulsion.
4. Place samples in Thermolyne programmable ashing furnace Model #F30430C. Program furnace to dry samples at 115°C for 800 minutes and ash at 500°C for 90 minutes with a 3°C/min ramp for both dwell temperatures.

Reduction Procedure

1. Add 10 mL Type I water to ashed samples.
2. Add 15 mL concentrated hydrochloric acid (analytical reagent grade).
3. Dissolve residue by heating (do not boil) for 10 minutes on a hot plate set at a temperature of 200°C.
4. Quantitatively transfer samples to 100 mL volumetric flasks. Samples must be analyzed within 24 hours.

Instrumental Conditions

Selenium samples are analyzed on a Varian Spectra 30 Atomic Absorption Spectrophotometer with a Vapor Generation Accessory (VGA) Model 76. The light source is provided by a Westinghouse electrodeless discharge lamp (EDL). Instrument parameters and selenite standard concentrations are described below (Table C-1).

1/ (May, T. 1982)

APPENDIX C. Analysis. (Continued)

Table C-1. Analytical Parameters for Hydride Generation Atomic Absorption Spectrophotometry

Varian Spectra 30 AA System parameters:

Instrument Parameters

Element	Se
Lamp Position	1
Lamp Current (mA)	5
Slit Width (nm)	1.0
Slit Height	Normal
Wavelength (nm)	196.0
Flame	Air-Acetylene
Sample Introduction	Auto Normal
Replicates	3
Measurement Time (sec)	8
Delay Time (sec)	40
Background Correction	Optional

Sample Changer

Rinse Rate	1
Rinse Time (sec)	30.0
Recalibration	8
Reslope Rate	0

Standards

Standard 1	0.0050
Standard 2	0.0100
Standard 3	0.0150
Standard 4	0.0200
Concentration units	ug/mL (PPM)

Selenite standards used must be of the same acid concentration as the samples. Reagents used with the VGA include concentrated hydrochloric acid (analytical reagent grade) and 0.33% sodium borohydride (w/w) stabilized with 0.5 percent sodium hydroxide (w/w) in Type I water.

For every batch of samples, the blank, sensitivity check, control materials, and duplicates are completed as described below. In addition, one or more samples of each kind of matrix in a batch are analyzed by standard addition to determine the matrix effect and the necessity to "spike" remaining samples.

APPENDIX C. Analysis. (Continued)

Blank

An analytical or procedural blank is carried through with each group of samples to determine Se contamination by reagents. Appropriate corrections are made to analytical results for samples based on the blank response.

Instrument Sensitivity Check

The sensitivity of the spectrophotometer is checked at the beginning of each group of samples. For an adequate sensitivity check, the resulting sensitivity response must be within the manufacturer's specifications. If not, the instrument is again optimized and recalibrated using appropriate standards to achieve maximum sensitivity.

Control Materials

Two or more different types of control materials are analyzed with each sample group. Control materials include (i) National Bureau of Standards (NBS) 50 tuna, (ii) NBS 1566 oyster, and (iii) NBS 1577a bovine liver. Reference material results are acceptable only when they are within the 95% confidence level.

Duplicates

A total of 10% of the samples are selected at random and analyzed in duplicate as a check of analytical precision.

WPCL HGAA Selenium Analysis Procedure f...

1. Pour approximately 25 ... of th...

APPENDIX C. Analysis. (Continued)

5. Cool the samples.
6. Add 10.0 mL Type I water to ashed samples.
7. Add 15.0 mL concentrated hydrochloric acid (analytical reagent grade).
8. Dissolve residue by heating (do not boil) for 10 minutes on a hot plate set at a temperature of 200°C.
9. Quantitatively transfer samples to 100 mL volumetric flasks if samples are suspected to contain more than 20 ug/L of selenium. Samples with low levels of selenium (< 20 ug/L) should not be diluted to 100 mL but poured directly into a clean autosampler test tube or can be analyzed directly from the beaker.

Instrumental Conditions

Analyze samples using instrumental conditions described above (WPCL Selenium Analysis Procedure for Tissue). All selenite standards and blank solutions must be made up with the same acid concentration as the samples.

WPCL HGAA Selenium Analysis Procedure for Sediment[2/]

Digestion Procedure

1. Place 0.2 to 0.7 g of the well mixed sediment sample into a 100 mL Pyrex beaker and cover with a watch glass.
2. Add 10 mL of reagent grade 50% $Mg(NO_3)_2 \cdot 6H_2O$, 50% H_2O (w/w).
3. Add 5 mL of concentrated nitric acid (ultra pure grade). To minimize foaming the nitric acid must be added slowly.
4. Place samples in Thermolyne programmable furnace Model #F30430C. Program furnace to dry samples at 115°C for 800 minutes and ash at 500° for 90 minutes with a 3°C/min ramp for both dwell temperatures.
5. Add 10 mL Type I water to ashed samples.
6. Add 15 mL concentrated hydrochloric acid (analytical reagent grade).
7. Dissolve residue by heating (do not boil) for 10 minutes on a hot plate set at a temperature of 200°C.
8. Quantitatively transfer samples to 100 mL volumetric flasks if samples are suspected to contain more than 0.5 ug/g of selenium. Samples with low levels of selenium (< 0.5 ug/g) should not be diluted to 100 mL but poured directly into a clean auto sampler test tube or can be analyzed directly from the beaker. Improved selenium recovery has been reported when samples are filtered.

APPENDIX C. Analysis. (Continued)

Instrumental Conditions

Analyze samples using instrumental conditions described above (WPCL Selenium Analysis Procedure for Tissue). All selenite standards and blank solutions must be made up with the same acid concentration as the samples. In addition, all samples are run twice, once unspiked and the second time with a selenite standard spike. The percent recovery of the added selenium is determined and the selenium concentration for each individual sample is calculated based on spike recovery.

WPCL Sample Moisture Determination

Samples are sub-sampled into a pre-weighed aluminum weighing dish. The dish with the wet sample is weighed and placed in an oven for 48 hours at 80°C. After drying, the weight of the dry dish with the sample is taken and recorded for moisture calculations.

Arsenic HGAA Analysis Procedure

The HGAA arsenic procedure is identical to the selenium procedure described above except for the following: an arsenic EDL at 193.7 nm is used, arsenic (III) is used for the standards, and 2 mL of 50% potassium Iodide (analytical reagent grade) is added to the volumetric flasks after step 4 of the reduction procedure and allowed to set in the dark for at least 1 hour. The VGA 76 has two sets of tubing, connections, and quartz cells. The set exposed to potassium iodide is only used for arsenic determinations. Also, any glassware that comes in contact with potassium iodide must be rinsed at least 5 times with type III water and stored in 0.5 M sodium hydroxide (reagent grade) for at least 24 hours.

GFAA Analysis Procedure

Analysis Sample Bottle Cleaning Procedure

1. Add 2 mL concentrated nitric acid (analytical reagent grade) to 30 mL narrow neck LPE bottles.
2. Fill with Type I water, screw on cap, and shake.
3. Allow to stand at least 24 hours.
4. Discard nitric acid solution and rinse with Type I water. Use bottle in Sample Preparation.

APPENDIX C. Analysis. (Continued)

Sample Preparation[2/]

1. Weigh 0.50 g of sample into a clean LPE bottle.
2. Add 2.0 mL concentrated nitric acid (ultra pure grade).
3. Cap and place in hot water bath (60-70° C) for 2 hours.
4. Allow to cool.
5. Open under hood with a towel around the cap.
6. Squeeze the bottle to remove nitrogen dioxide fumes.
7. Add 17.5 mL of Type I water.
8. Cap and tumble in hot water bath for 30 minutes.
9. Allow to cool.

Instrumental Conditions

Samples containing elements of interest in concentrations above Flame Atomic Absorption Spectrophotometry (FAA) detection limits

APPENDIX C. Analysis. (Continued)

3. Place the flasks upside-down, on paper towels, to dry.

Preparation of Samples

1. Place (0.50±0.05)g of the tissue to be analyzed into a clean 125 ml erlenmeyer flask. Deposit the sample on the bottom of the flask only. Record the weight of the sample to the nearest 0.01 g. For every analysis (16 samples), prepare two duplicates, two blanks, and two NBS 50 (Tuna) research materials.

2. Add 5.0 ml concentrated (18M) H_2SO_4 to the flasks and cover the flasks with the 50 ml beaker.

3. Place the flasks on a hot plate at 50°-60°C to digest the sample. Two hours is normally sufficient. Digestate should be light brown in color and clear.

4. After the sample has been digested, place the flasks in an ice bath to cool.

5. In the fume hood, add 30.0 ml of a 6% $KMnO_4$ solution to the flasks without mixing. After all the $KMnO_4$ has been added, swirl the flasks' contents until the rapid evolution of gases cease.

6. Place the flasks on a hot plate and allow the samples to digest further. Swirl the flasks occasionally and continue to heat the contents until all of the foam disappears (usually 30 minutes to one hour).

7. If any samples have turned brown, add 5.0 ml of $KMnO_4$ to every sample and blank. Repeat if necessary to retain purple color.

8. Heat the sample just to the point that the solution begins to reflux from the neck of the flask.

9. Remove the flasks from the heat and allow them to cool in the hood to room temperature. Analyze the flasks'contents for total mercury by atomic absorption.

Preparation of Reagents

1. 10% $NH_2OH*HCl$ (hydroxylamine hydrochloride) solution: Dissolve 10 g $NH_2OH*HCl$ into 100 ml of deionized H_2O. Bubble air (or nitrogen) through the solution to remove any mercury.

APPENDIX C. Analysis. (Continued)

2. 10% $SnCl_2$ (stannous chloride) solution:
Dissolve 5 g $SnCl_2*2H_2O$ in 10 ml 6N HCl. Dilute this solution to 50 ml with deionized H_2O. Bubble air (or nitrogen) through the solution to remove any mercury.

3. 6% $KMnO_4$ (potassium permanganate) solution:
Dissolve 60 g $KMnO_4$ into 1000 ml deionized H_2O and shake vigorously. Allow the solution to stand for two hours.

Preparation of Standards

1. Mercury standard solution - 1000 ppm:
Dissolve 0.1354 g of mercuric chloride ($HgCl_2$) into to 50 ml deionized H_2O containing 0.8 ml 6N HCl. Dilute to 100 ml with deionized H_2O.

2. Intermediate mercury standard solution - 5 ppm:
Add 8.0 ml 6N HCl and 200 ml of deionized H_2O to a 1000 ml volumetric flask. To this, add 5.00 ml of the 1000 ppm standard and dilute to volume with deionized H_2O. Prepard fresh weekly.

3. Working mercury standard solution - 0.5 ppm:
Add a partial drop of the 6% $KMnO_4$ solution to a 50 ml volumetric flask, dilute with deionized water until solution is light pink and volumetric is about one-half full. Add 0.4ml 6N HCl to the solution. Add 5.00 ml of the 5.00 ppm intermediate standard solution, dilute to volume with deionized H_2O, and mix.

(1 ml = 0.5 ug Hg)

Instrumental Conditions

Samples are analyzed for total mercury using the cold vapor technique on a Varian Model 475 equipped with a cylindrical spectrophotometer cell, 18 cm path length, with quartz windows and two filler necks. A heat lamp is used to keep water vapor from condensing on the inside of the cell. The light source is provided by a Varian hollow cathode lamp operated at 4 milliamps. The slit width is set at 1 nm and a wavelength of 253.7nm is used.

Nitrogen is used as the sample aeration gas at a flow rate of 1 L per minute.

1. The digested sample is carefully transferred from the 125 ml erlenmeyer flask to a 250 ml gas washing bottle equipped with a glass tube with a fritted cylinder. The bottle containing a stirring bar should be on a magnetic stirrer. The erlenmeyer flask is rinsed with water and then with a small

APPENDIX C. Analysis. (Continued)

amount of hydroxylamine*HCl solution to remove the brown oxides formed during the permanganate digestion and finally a third wash with water. Transfer these washes to the to the gas washing bottle, rinsing the sides of the bottle until the volume in the bottle reaches 125 ml. Turn on the magnetic stirrer.

2. Add hydroxylamine*HCl solution until the purple solution turns clear (2-4 ml).

3. Add two ml of the stannous chloride solution and immediately replace the top of the bottle with the fritted cylinder and turn on the nitrogen purge gas.

4. Mercury is measured by peak height from a strip chart recorder.

5. Standards are analyzed by adding the standard solution directly to a "spent" sample solution after all the mercury has been removed by aeration. The stirrer and nitrogen flow are stopped, the top is removed from the gas washing bottle, and an amount of standard is added to the solution in the bottle. The top is immediately replaced and the stirrer and the nitrogen flow is turned on.

6. The amount of mercury in the sample is calculated as follows:

$$\text{ug Hg in sample} = \text{sample peak height} \times \frac{\text{Standard amount (ug Hg)}}{\text{Standard Peak Height}}$$

$$\text{Sample concentration (ug/g Hg)} = \frac{\text{ug Hg in Sample}}{\text{Sample weight}}$$

Blanks

Two procedural blanks are run with each set of 16 samples.

Instrument Sensitivity Check

The sensitivity of the spectorphotometer is checked at the beginning of each set of samples. For an adequate sensitivity check, the instrument response must be within manufacturer's specifications. If not, the instrument is again optimized and standards are again analyzed to recheck sensitivity.

Control Materials

Tuna research material (NBS 1566) is run in duplicate with each set of samples. These results are acceptable when they are within the 95% confidence limits reported by the National Bureau of Standards.

APPENDIX D. WPCL Results of Duplicate Selenium Analyses.

Sample #	SE ug/g (ppm) Wet Weight		Mean	% RSD[1/]
BIRDS				
B1260F	2.5	2.5	2.5	0
B2007F	3.5	3.6	3.6	2.0
B2010F	5.7	5.6	5.6	1.2
B2039F	0.79	0.81	0.80	1.8
B2041F	0.68	0.67	0.68	1.0
B2042F	2.3	2.3	2.3	0
B2043F	0.94	0.94	0.94	0
B2045F	2.0	2.1	2.0	3.4
B2046F	0.40	0.41	0.40	1.7
B2053F	0.52	0.57	0.54	6.5
B2061F	3.1	3.2	3.2	2.2
B2070F	1.7	1.8	1.8	4.0
B2109F	10.	10.	10.	0
B2129F	6.5	6.7	6.6	2.1
B1260L	15.	15	15	

APPENDIX C. Analysis. (Continued)

Duplicates

A total of at least 10% of the samples are selected at random and analyzed in duplicate as a check of analytical precision.

Citations

Adrian, W.J. 1971. A new wet digestion method for biological material utilizing pressure. Atomic Absorption Newsletter 10(4):96.

May, T.W. 1982. Recovery of endgenous selenium from fish tissues by open system dry ashing. J. Assoc. Anal. Chem. 65:1140-44.

APPENDIX D. WPCL Results of Duplicate Selenium Analyses. (Continued)

Sample #	Se ug/g (ppm) Wet weight		Mean	% RSD[1/]
FISH				
F2094F	0.16	0.19	0.18	12.
F2099F	0.17	0.16	0.16	4.3
F2028L	5.3	5.3	5.3	0
F2037L	3.0	3.2	3.1	4.6
F2050L1	1.9	1.9	1.9	0
F2063L	2.6	2.6	2.6	0
F2068L	1.7	1.8	1.8	4.0
F2092L	0.97	1.0	0.98	2.2
F2105L	1.4	1.4	1.4	0
F2107L	2.4	2.4	2.4	0
INVERTEBRATES				
I2002	0.48	0.49	0.48	1.4
I2004	0.16	0.20	0.18	16.
I2015	0.81	0.80	0.80	0.89
I2025W2	2.2	2.3	2.2	3.1
I2026	0.89	0.83	0.86	4.9
I2027	0.81	0.81	0.81	0
I2038W	0.58	0.58	0.58	0

Mean RSD for HGAA values = 2.2 percent

1/ Relative Standard Deviation (RSD) = (standard deviation/mean) x 100

APPENDIX D WRCL Results of Reanalysis

[redacted]

SAMPLE #	SE ug/L (PPB)		MEAN	% RSD[1/]
WATER				
L2033	69.	72.	70.	3.0
L2039	<0.2	<0.2	<0.2	0
L2041	160.	160.	160.	0
L2042	450.	450.	450.	0
L2043	100.	100.	100.	0
L2044	2.9	2.9	2.9	0
L2046	<1.0	<1.0	<1.0	0
L2049	4.3	4.4	4.4	1.6
L2051	<1.0	<1.0	<1.0	0
L2052	1.0	0.8	0.9	15.
L2053	<1.0	<1.0	<1.0	0
L2054	<1.0	<1.0	<1.0	0
L2055	<1.0	<1.0	<1.0	0
L2056	<1.0	<1.0	<1.0	0
L2057	<1.0	<1.0	<1.0	0
L2058	<1.0	<1.0	<1.0	0
L2062	59.	59.	59.	0
L2064	17.	16.	16.	4.4
L2065	5.3	5.2	5.2	1.4
L2066	13.	13.	13.	0
L2067	100.	100.	100.	0.67
L2068	<1.0	<1.0	<1.0	0
L2069	4.1	3.0	3.6	21.
L2070	7.2	6.8	7.0	4.0
L2071	2.6	2.2	2.4	11.

SAMPLE #	SE ug/g (ppm) Dry Weight		MEAN	% RSD
SEDIMENT				
S2010	0.27	0.23	0.25	11.

APPENDIX D. WPCL Results of Duplicate Moisture Determination

Sample #	% Moisture Duplicate		Mean	% RSD[1/]
BIRDS				
B1260F	72	72	72	0
B2007F	72	72	72	0
B2039F	73	73	73	0
B2041F	72	72	72	0
B2043F	73	72	72	0.98
B2045F	73	73	73	0
B2046F	73	73	73	0
B2053F	73	72	72	0.98
B2061F	73	73	73	0
B2070F	72	72	72	0
B2109F	73	73	73	0
B2129F	73	74	74	0.96
B1260L	70	70	70	0
B2002L	71	71	71	0
B2005L	69	69	69	0
B2014L	71	71	71	0
B2042L	72	72	72	0
B2047L	74	74	74	0
B2054L	73	73	73	0
B2062L	72	72	72	0
B2072L	71	71	71	0
B2082L	68	69	68	1.0
B2092L	71	70	70	1.0
B2102L	71	71	71	0
B2112L	70	70	70	0
B2128L	74	74	74	0
B2134L	74	74	74	0
FISH				
F2019F	78	78	78	0
F2020F	78	78	78	0
F2035F	80	80	80	0
F2049F	75	76	76	0.94
F2069F	79	78	78	0.90
F2077F	76	76	76	0
F2078F	78	78	78	0
F2081F	79	79	79	0
F2083F	75	76	76	0.94
F2094F	79	79	79	0
F2099F	79	79	79	0

1/Relative Standard Deviation (RSD) = (standard deviation/mean x 100.

APPENDIX D. WPCL Results of Duplicate Moisture Determination. (Continued)

Sample #	% Moisture Duplicate		Mean	% RSD[1/]
FISH				
F2028L	79	79	79	0
F2050L1	77	77	77	0
F2063L	79	79	79	0
F2068L	79	79	79	0
F2092L	81	81	81	0
F2105L	81	81	81	0
F2107L	80	80	80	0
INVERTEBRATES				
I2002	50	53	52	4.1
I2004	77	78	78	0.91
I2015	86	86	86	0
I2027	86	86	86	0
I2038W	91	91	91	0
P2035	73	74	74	0.96
P2044	93	93	93	0

Mean RSD for moisture content = 0.26 percent

1/Relative Standard Deviation (RSD) = (standard deviation/mean) x 100.

APPENDIX E. Results of the Nine Element Round-Robin in ug/g (ppm) dry weight.

Sample # B1089-95L Element	NAA[1/]	VDTL[2/]	WPCL
Arsenic	0.86	0.88	0.72
Cadmium	9.0	8.1	8.1
Chromium	<0.1	<0.037	<0.8
Copper	290.	270.	260.
Lead	-	0.17	<0.4
Mercury	4.6	1.6	2.0
Selenium	100.	81.	100.
Silver	4.	3.9	3.9
Zinc	138.	150.	150.

Sample # B1145-51L Element	NAA	VDTL	WPCL
Arsenic	2.0	1.7	1.5
Cadmium	10.	5.9	6.2
Chromium	0.07	<0.038	<0.08
Copper	82.	56.	58.
Lead	-	0.43	0.4
Mercury	3.6	2.1	2.2
Selenium	13.	12.	12.
Silver	0.2	0.15	0.13
Zinc	138.	140.	140.

1/ Neutron Activation Analysis performed by the University of Missouri

2/ The dry weight VDTL results were obtained by using the moisture determinations done at WPCL.

APPENDIX E. Results of the Nine Element Round-Robin in ug/g (ppm) dry weight. (Continued)

Sample # B1317-21L Element	NAA[1/]	VDTL[2/]	WPCL
Arsenic	1.0	0.93	0.73
Cadmium	11.	5.5	5.7
Chromium	0.2	<0.036	<0.08
Copper	73.	56.	57.
Lead	-	0.37	0.4
Mercury	7.7	3.6	5.2
Selenium	160.	130.	150.
Silver	0.5	0.48	0.39
Zinc	123.	120.	120.

Sample # B1339-43L Element	NAA	VDTL	WPCL
Arsenic	1.1	0.92	0.81
Cadmium	14.	7.6	8.1
Chromium	<0.1	<0.037	<0.08
Copper	110.	89.	91.
Lead	-	0.15	<0.4
Mercury	11.	7.4	7.8
Selenium	22.	18.	19.
Silver	0.3	0.2	0.18
Zinc	174.	170.	170.

1/ Neutron Activation Analysis performed by the University of Missouri

2/ The dry weight VDTL results were obtained by using the moisture determinations done at WPCL.

APPENDIX E. Results of the Nine Element Round-Robin in ug/g (ppm) dry weight. (Continued)

Sample # F1008 L1,2,3

Element	NAA[1/]	VDTL[2/]	WPCL
Arsenic	0.22	0.19	0.20
Cadmium	<10.	0.17	0.19
Chromium	0.5	<0.048	<0.10
Copper	31.	23.	24.
Lead	-	0.10	<0.5
Mercury	0.52	0.52	0.36
Selenium	5.3	5.7	5.2
Silver	0.04	0.038	<0.1
Zinc	109.	120.	120.

Sample # F1029 L1,2,3

APPENDIX E. Results of the Nine Element Round-Robin in ug/g (ppm) dry weight. (Continued)

Sample # F1032 L1,2,3

Element	NAA[1/]	VDTL[2/]	WPCL
Arsenic	0.19	0.19	0.21
Cadmium	<10.	0.23	0.21
Chromium	<0.1	<0.053	<0.10
Copper	29.	18.	19.
Lead	-	0.20	<0.5
Mercury	0.83	0.74	0.47
Selenium	7.1	7.7	7.4

[redacted]

Sample # F1036 L1,2,3

Element	NAA	VDTL	WPCL
Arsenic	<0.4	0.22	0.30
Cadmium	<10.	0.24	0.20
Chromium	<0.1	<0.05	<0.10
Copper	<30.	16.	18.
Lead	-	0.23	<0.5
Mercury	1.4	1.2	0.72
Selenium	7.6	7.8	7.5
Silver	<0.05	0.02	<0.1
Zinc	96.6	100.	100.

1/ Neutron Activation Analysis performed by the University of

Appendix F. Trace Metals in Fish Tissue Reported in mg/kg, Dry Weight.
(Samples analyzed by neutron activation, University of Missouri).

	F1008L 1,2,3	B1089 -95L	F1036L 1,2,3	B1339	B1145 -51L	B1317 -21L	F1029L 1,2,3	F1032L 1,2,3
Chlorine	6650.	5390.	7920.	4900.	5670.	5220.	9540.	8330.
Copper	31.	290.	<30.	110.	82.	73.	<30.	29.
Iodine	4.	4.	4.	4.	<2.	2.	20.	7.
Manganese	<5.	24.	15.	19.	20.	24.	7.5	16.
Cadmium	<10.	9.0	10.	14.	10.	11.	<10.	<10.
Arsenic	0.22	0.86	<0.4	1.1	2.0	1.0	0.47	0.19
Sodium	4270.	3910.	5480.	4210.	4570.	4480.	6600.	5670.
Potassium	12800.	10700.	14700.	11600.	10500.	11200.	14300.	13600.
Thorium	0.7	0.6	0.7	<0.5	0.4	0.3	0.3	0.4
Silver	0.04	4.	<0.05	0.3	0.2	0.5	<0.05	0.1
Chromium	0.5	<0.1	<0.1	<0.1	0.07	0.2	0.1	<0.1
Zinc	109.	138.	96.6	174.	138.	123.	107.	96.3
Selenium	5.3	100.	7.6	22.	13.	160.	13.	7.1
Mercury	0.52	4.6	1.4	11.	3.6	7.7	0.99	0.83
Boron	37.	19.	35.	58.	23.	22.	71.	33.
Cobalt	0.12	0.21	0.60	0.31	0.27	0.23	0.17	0.72
Iron	1050.	3930.	1100.	1770.	3460.	2450.	1080.	1060.
Rubidium	9.7	8.7	7.8	11.	8.4	8.1	3.5	7.5

APPENDIX G. Comparison of VDTL and WPCL Selenium Values and % RSD in Bird, Fish and Invertebrates. Results Reported in ug/g (ppm).

SAMPLE	SELENIUM Wet Weight VDTL	WPCL	%RSD	SAMPLE	SELENIUM Wet Weight VDTL	WPCL	%RSD
BIRDS				BIRDS			
B1047L	13.36	14.	3.3	B1251L	2.51	2.4	3.2
B1048L	18.50	18.	1.9	B1252L	2.00	2.1	3.4
B1049L	4.33	4.2	2.2	B1253L	1.64	1.6	1.7
B1050L	6.06	4.9	15.	B1254L	1.27	1.4	6.9
B1051L	23.5	23.	15.	B1255L	1.11	1.2	5.5
B1052L	12.9	14.	5.8	B1256L	1.80	1.9	3.8
B1053L	10.8	10.	5.4	B1260L	15.0	15.	0.
B1097L	2.23	2.3	2.2	B1261L	14.1	14.	0.50
B1098L	0.68	0.68	0.	B1262L	20.6	21.	1.4
B1099L	5.48	4.7	11.	B1263L	20.5	21.	1.7
B1100L	2.62	2.3	9.2	B1264L	17.6	17.	2.4
B1101L	0.83	0.90	5.7	B1265L	1.50	1.6	4.6
B1102L	0.89	0.87	1.6	B1266L	1.73	1.8	2.8
B1103L	2.00	2.0	0.	B1268L	0.86	0.92	4.8
B1167L	30.0	27.	7.4	B1269L	1.71	1.8	3.6
B1168L	22.4	23.	1.9	B1270L	1.91	2.1	6.7
B1169L	16.5	18.	6.1	B1271L	1.81	1.8	0.39
B1170L	27.8	25.	7.5	B1353L	5.68	6.0	3.9
B1171L	11.4	11.	2.5	B1354L	10.7	11.	2.0
B1172L	28.5	26.	6.5	B1355L	18.8	17.	7.1
B1173L	28.4	28.	1.0	B1356L	4.40	3.8	10.
B1177L	2.23	2.4	5.2	B1357L	22.5	22.	1.6
B1178L	1.05	1.0	3.4	B1358L	13.3	13.	1.6
B1179L	1.61	1.6	0.44	B1359L	12.3	11.	7.9
B1180L	1.76	1.7	2.4	B2001L	32.2	32.	0.44
B1181L	1.80	1.8	0.	B2002L	18.7	18.	2.7
B1182L	1.85	1.8	1.9	B2003L	19.1	19.	0.37
B1183L	1.16	1.2	2.4	B2004L	18.8	19.	0.75
B1184L	1.98	1.8	6.7	B2005L	21.8	20.	6.1
B1200L	26.4	26.	1.1	B2006L	22.3	22.	0.96
B1201L	25.8	23.	8.1	B2007L	39.8	36.	7.1
B1202L	12.1	12.	0.59	B2008L	38.1	36.	4.0
B1203L	23.5	23.	1.5	B2009L	46.6	45.	2.5
B1204L	33.1	32.	2.4	B2010L	47.7	45.	4.1
B1205L	29.6	28.	3.9	B2011L	52.1	50.	2.9
B1206L	42.2	41.	2.0	B2012L	26.3	26.	0.81
B1207L	16.6	19.	9.5	B2013L	17.3	17.	1.2
B1216L	22.0	23.	3.1	B2014L	29.0	28.	2.5
B1237L	30.7	27.	9.1	B2015L	19.4	17.	9.3
B1238L	39.8	40.	0.35	B2016L	27.1	26.	2.9
B1249L	1.77	1.7	2.8	B2017L	18.7	18.	2.7
B1250L	2.44	2.6	4.5	B2018L	21.0	19.	7.1

APPENDIX G. Comparison of VDTL and WPCL Selenium Values and % RSD in Bird, Fish and Invertebrates. Results Reported in ug/g (ppm). (Continued)

SAMPLE	SELENIUM Wet Weight VDTL	WPCL	%RSD	SAMPLE	SELENIUM Wet Weight VDTL	WPCL	%RSD
BIRDS				BIRDS			
B2019L	44.6	41.	5.9	B2096L	33.3	31.	5.1
B2020L	20.6	20.	2.1	B2097L	23.8	18.	20.
B2062L	16.5	15.	6.7	B2098L	32.0	26.	15.
B2063L	14.6	14.	3.0	B2099L	2.87	3.0	3.1
B2064L	6.81	6.4	4.4	B2100L	21.0	16.	19.
B2065L	20.5	21.	1.7	B2101L	2.64	2.3	9.7
B2066L	6.68	6.9	2.3	B2102L	47.9	43.	7.6
B2067L	14.8	15.	0.95	B2103L	45.6	41.	7.5
B2068L	11.6	11.	3.8	B2104L	56.5	51.	7.2
B2069L	13.0	13.	0.	B2105L	57.5	54.	4.4
B2070L	6.91	6.5	4.3	B2106L	46.3	43.	5.2
B2071L	12.2	12.	1.2	B2107L	63.5	58.	6.4
B2072L	14.9	14.	4.4	B2108L	74.4	71.	3.3
B2073L	8.25	8.4	1.3	B2109L	79.5	71.	8.0
B2074L	9.18	9.6	3.2	B2110L	59.7	55.	5.8
B2075L	1.64	1.8	6.6	B2111L	58.4	50.	11.
B2076L	8.78	8.5	2.3	B2112L	67.6	61.	7.2
B2077L	16.2	15.	5.4	B2113L	58.9	52.	8.8
B2078L	2.52	3.0	12.	B2114L	59.7	53.	8.4
B2079L	4.06	4.1	0.69	B2115L	59.7	55.	5.8
B2080L	17.2	18.	3.2	B2116L	69.9	62.	8.5
B2081L	4.52	4.5	0.31	B2117L	63.2	56.	8.5
B2082L	4.33	4.2	2.2	B2118L	76.6	67.	9.4
B2083L	1.40	1.5	4.9	B2119L	94.7	84.	8.5
B2084L	1.89	2.0	4.0	B2120L	50.0	45.	7.4
B2085L	1.62	1.7	3.4	B2121L	58.4	52.	8.2
B2086L	2.76	2.4	9.9	B2134L	17.5	16.	6.3
B2087L	20.1	17.	12.	B2135L	37.3	33.	8.6
B2088L	1.73	1.8	2.8	B2136L	24.7	22.	8.2
B2089L	1.40	2.0	25.	B2137L	50.6	45.	8.3
B2090L	2.01	2.0	0.35	B2138L	58.6	51.	9.8
B2091L	1.76	1.7	2.4	B2139L	46.0	41.	8.1
B2092L	35.2	27.	19.	B2140L	38.7	34.	9.1
B2093L	7.78	6.4	14.	B2141L	50.6	45.	8.3
B2094L	16.4	13.	16.	B2142L	52.8	46.	9.7
B2095L	28.7	23.	16.	B2143L	49.6	44.	8.5
FISH				FISH			
F2001L	4.17	4.0	2.9	F2011L	*	2.3	-
F2002L	4.60	4.4	3.1	F2012L	*	2.7	-
F2003L	4.26	4.2	1.0	F2015L	2.26	2.4	4.2
F2004L	*	2.1	-	F2016L	*	2.9	-
F2005L	*	2.3	-	F2017L	2.68	2.7	0.53
F2008L	*	1.6	-	F2018L	*	1.4	-
F2009L	*	2.1	-	F2019L	1.59	1.6	0.44

APPENDIX G. Comparison of VDTL and WPCL Selenium Values and %RSD in Bird, Fish and Invertebrates. Results Reported in ug/g (ppm). (Continued)

SAMPLE	SELENIUM Wet Weight VDTL	WPCL	%RSD
FISH			
F2020L	*	2.6	-
F2021L	1.90	1.9	0.
F2022L	7.00	6.8	2.0
F2023L	3.87	3.3	11.
F2024L	2.70	2.7	0.
F2026L	3.70	3.6	1.9
F2027L	6.00	5.8	2.4
F2028L	5.50	5.3	2.6
F2031L	2.60	2.5	2.8
F2034L	*	1.5	-
F2037L	3.27	3.1	3.8
F2040L	*	2.4	-
F2043L	1.41	1.4	0.50
F2044L	*	1.2	-
F2048L	4.0	3.6	7.4
F2049L	2.70	2.7	0.
F2050L1	2.13	1.9	8.1
F2050L2	2.09	2.1	0.34
F2050L3	2.30	2.4	3.0
F2051L	2.77	2.6	4.5
F2052L	1.94	1.7	9.3
F2053L	2.28	2.0	9.2
F2054L	1.58	1.5	3.7
F2055L	1.48	1.5	0.95
FISH			
F2056L	1.68	1.8	4.9
F2057L	1.22	1.4	9.7
F2058L	0.93	1.0	5.1
F2059L	1.86	1.9	1.5
F2060L	1.58	1.6	0.89
F2061L	1.72	1.7	0.83
F2062L	2.22	2.2	0.64
F2063L	2.63	2.6	0.81
F2064L	2.71	2.5	5.7
F2065L	2.61	2.6	0.27
F2066L	1.35	1.7	16.
F2067L	1.10	0.97	8.9
F2068L	1.70	1.8	4.0
F2069L	1.67	1.7	1.2
F2070L	1.80	1.8	0.
F2071L	1.78	2.1	12.
F2072L	2.05	3.2	31.
F2073L	2.76	2.9	3.5
F2074L	1.09	1.8	35.
F2075L	1.57	1.5	3.2
F2076L	1.35	1.8	20.
F2077L	3.48	3.4	1.6
F2078L	3.70	3.4	6.0

* = SAMPLE EXHAUSTED

APPENDIX G. Comparison of VDTL and WPCL Selenium Values and % RSD in Bird, Fish and Invertebrates. Results Reported in ug/g (ppm). (Continued)

SAMPLE	SELENIUM Dry Weight VDTL	WPCL	%RSD
INVERTEBRATES			
I2001F1	5.34	7.2	21.
I2001F2	5.69	5.5	2.0
I2002	0.88	0.99	8.3
I2003	0.76	0.50	29.
I2005	1.15	0.63	41.
I2006	1.25	1.5	12.
I2007	1.20	1.3	6.2
I2008	0.38	0.54	25.
I2009	1.49	3.8	61.
I2010	1.29	1.9	27.
I2011	1.44	1.1	19.
I2012	0.72	1.0	24.
I2013	0.89	1.4	30.
I2016	5.74	5.5	3.5
I2017	0.99	0.91	5.6
I2018	1.02	0.90	8.8
INVERTEBRATES			
I2019	1.86	1.9	2.6
I2020	1.97	1.7	9.2
I2022	2.28	2.3	0.92
I2023	46.33	46.	0.05
I2024W1	15.52	16.	0.18
I2024W2	17.87	16.	9.8
I2025W1	10.74	8.0	21.
I2025W2	14.44	12.	16.
I2026	6.61	5.7	10.
I2027	6.14	5.8	4.3
I2028	5.31	5.7	5.1
I2029	5.59	5.7	1.2
I2030	1.08	1.4	20.
I2031	1.90	0.96	46.
I2032	1.22	1.1	9.9

APPENDIX H

Selenium concentrations in water (ug/kg, ppb), suspended particulates (ppm), plankton (ppm) and sediments (ppm) collected in 1987-1988. Negative numbers represent a value less than the number listed, which was the detection limit for that sample.

1987-88 SELENIUM LEVELS IN COMPONENTS OF THE AQUATIC ENVIRONMENT

SAMPLE DATE	SAMPLE LOCATION	SUBSITE	TIDE	SEDIMENT WET WGHT (ppm)	SEDIMENT DRY WGHT (ppm)	WATER (ppb)	PARTICULATES DRY WGHT (ppm)	PLANKTON DRY WGHT (ppm)
** LOCATION	CMP13							
09/01/87	CMP13			0.52	0.79			
01/13/88	CMP13			0.50	0.75	70.00	2.40	2.10
03/08/88	CMP13			0.86	1.40	62.00	1.60	1.50
04/26/88	CMP13			0.38	0.71	104.00		0.54
** LOCATION	HMBLT							
01/29/88	HMBLT		H			0.06	0.27	-0.20
01/29/88	HMBLT		L	0.11	0.25	0.05	0.37	-0.20
** LOCATION	MAZEB							
09/10/87	MAZEB			-0.04	-0.06			
09/10/87	MAZEB			-0.04	-0.05			
11/06/87	MAZEB			0.15	0.42	1.20	1.20	0.28
01/19/88	MAZEB			0.10	0.14	2.50	0.91	0.11
03/10/88	MAZEB			0.16	0.35	5.20	1.40	0.38
04/29/88	MAZEB			0.15	0.28	3.60	1.70	0.54
** LOCATION	MEYER							
02/04/88	MEYER	CELL2		0.05	0.41	0.30	1.80	-0.08
02/04/88	MEYER	CELL1		0.11	0.84	-0.20	1.10	-0.20
** LOCATION	MUDSL							
09/02/87	MUDSL			0.70	1.30			
11/04/87	MUDSL			0.36	0.63	1.00	2.10	0.64
01/13/88	MUDSL			0.28	0.81	5.30	1.60	0.58
03/07/88	MUDSL			0.22	0.31	20.00	1.20	0.92
05/02/88	MUDSL			0.34	0.57	2.40	2.70	0.19
** LOCATION	PRYSE							
02/03/88	PRYSE	CELL1		0.82	1.70	7.90	4.80	1.70
** LOCATION	SALTS							
09/03/87	SALTS			0.19	0.31			
11/05/87	SALTS			0.25	1.30	3.30	1.40	0.76
01/14/88	SALTS			0.36	1.10	19.00	2.10	0.91
03/09/88	SALTS			0.41	1.10	16.00	1.20	0.70
04/26/88	SALTS			0.58	1.40	13.00		0.17
** LOCATION	SJRLN							
09/02/87	SJRLN			-0.04	-0.05			
11/04/87	SJRLN					-0.20	0.98	-0.08
01/13/88	SJRLN			-0.04	-0.07	5.00	1.00	0.16
03/08/88	SJRLN			-0.04	-0.06	0.50	1.20	0.15
04/27/88	SJRLN			0.03	0.04	0.80		0.13

1987-88 SELENIUM LEVELS IN COMPONENTS OF THE AQUATIC ENVIRONMENT

SAMPLE DATE	SAMPLE LOCATION	SUBSITE	TIDE	SEDIMENT WET WGHT (ppm)	SEDIMENT DRY WGHT (ppm)	WATER (ppb)	PARTICULATES DRY WGHT (ppm)	PLANKTON DRY WGHT (ppm)
** LOCATION	SJRMR							
09/10/87	SJRMR			0.13	0.19			
11/06/87	SJRMR			0.15	0.75	1.60	1.70	0.40
01/15/88	SJRMR			0.12	0.28	6.10	2.20	0.36
03/09/88	SJRMR			0.18	0.47	10.00	1.30	0.38
04/29/88	SJRMR			0.29	0.46	7.00	1.70	0.33
** LOCATION	SNPBB							
11/23/87	SNPBB	CHCMP	H				0.32	-0.20
11/23/87	SNPBB	PETLR	H				0.37	-0.01
11/23/87	SNPBB	WILPT	L	0.09	0.30	0.05	0.31	-0.20
11/23/87	SNPBB	CSTCV	L	0.11	0.24	0.13	0.35	0.26
11/23/87	SNPBB	PETLR	L	0.11	0.20	0.14	0.36	-0.08
11/23/87	SNPBB	WILPT	H			0.14	0.36	-0.20
11/23/87	SNPBB	CHCMP	L	0.10	0.25	0.19	0.33	-0.20
11/23/87	SNPBB	CSTCV	H				0.29	0.20
02/25/88	SNPBB	CHCMP	L	0.14	0.29	0.15	0.42	-0.10
02/25/88	SNPBB	CSTCV	L	0.10	0.17	0.12	0.48	-0.20
02/25/88	SNPBB	WILPT	L	0.11	0.30	0.17	0.45	-0.20
02/25/88	SNPBB	PETLR	L	0.12	0.29	0.17	0.64	-0.20
02/26/88	SNPBB	CHCMP	H			0.11	0.42	-0.10
02/26/88	SNPBB	CSTCV	H			0.14	0.38	-0.20
02/26/88	SNPBB	WILPT	H			0.14	0.47	0.10
02/26/88	SNPBB	PETLR	H			0.15	0.65	-0.10
** LOCATION	SUISB							
10/14/87	SUISB		L	-0.04	-0.06	0.12	0.49	0.13
10/15/87	SUISB		H			0.17	0.53	
12/02/87	SUISB		H			0.13	0.36	-0.01
12/02/87	SUISB		L	-0.04	-0.06	0.09	0.39	-0.20
02/22/88	SUISB		L			0.19	0.35	0.20
02/22/88	SUISB		H	-0.04	-0.06	0.21	-0.01	-0.01
** LOCATION	WFRMR							
02/03/88	WFRMR	CELL2		0.56	0.91	460.00	6.20	1.90
02/03/88	WFRMR	CELL1		1.00	1.90	160.00	24.00	4.90
02/03/88	WFRMR	CELL3		0.76	1.10	100.00	9.70	1.50
** LOCATION	WLAKE							
02/03/88	WLAKE	CELL1		0.13	0.25	2.90	3.00	0.33
02/04/88	WLAKE	CELL6		0.08	0.15	4.40	0.49	0.16
02/04/88	WLAKE	CELL4		0.21	0.41	2.70	1.00	0.65

APPENDIX I. Comparison of USGS Reference Water Samples with VDTL Values in ug/L (ppb).

Sample I.D.	USGS T93	VDTL VALUE (T93) L2901	USGS T95	VDTL VALUE (T95) L2902
Aluminum	172. (44)	190.	30. (-)	140.
Arsenic	5.6 (1.6)	6.	.96 (.55)	1.
Boron	-	50.	1140. (82)	1210.
Barium	69. (12)	77.	48.3(15.3)	49.
Beryllium	7.2 (1.5)	6.	-	1.
Cadmium	4.8 (.6)	4.	.45 (.26)	2.
Chromium	9.8 (2.8)	10.	3.9 (3.4)	1.
Copper	30.6 (3.6)	35.	10.9 (4.3)	10.
Iron	100. (12)	100.	11. (6.8)	<5.
Lead	11.2 (3.5)	11.	3.9 (2.6)	2.
Lithium	21.6 (2.4)	20.	29.1 (4.8)	20.
Magnesium	-	2000.	32800. (1600)	31300.
Manganese	99. (4)	120.	4.0 (2.0)	<1.
Mercury	0.24 (.16)	<0.2	0.45 (0.07)	0.2
Molybdenum	19.4 (2.7)	24.	9.4 (3.8)	10.
Nickel	11.8 (3.0)	20.	2.5 (-)	<20.
Selenium	5.5 (.7)	5.4	60.1(15.3)	69.4
Silver	2.8 (1.3)	<5.	1.7 (0.9)	<5.
Vanadium	-	<6.	25. (38)	<6.
Zinc	27.8 (4.4)	27.	17.6 (4.4)	15.

APPENDIX I. Comparison of USGS Reference Water Samples with VDTL Values in ug/L (ppb). (Continued)

Sample I.D.	USGS T97	VDTL VALUE (T97) L2903
Aluminum	126. (42)	180.
Arsenic	11.3 (1.5)	12.
Boron	367. (101)	440.
Barium	98. (12)	108.
Beryllium	-	<1.
Cadmium	16.3 (2.3)	17.
Chromium	26.0 (4.3)	25.
Copper	16.8 (2.5)	18.
Iron	100. (9)	110.
Lead	15. (3.7)	16.
Lithium	47.7 (7.7)	40.
Magnesium	18900. (1000)	18300.
Manganese	30.5 (3.2)	40.
Mercury	0.9 (0.2)	0.7
Molybdenum	35.7 (3.6)	37.
Nickel	15.2 (5.8)	<20.
Selenium	15.9 (3.4)	17.4
Silver	7.0 (1.8)	8.
Vanadium	7.2 (1.3)	6.
Zinc	153. (10)	153.

Appendix J. Percent occurrence of food items in diving ducks from the San Francisco Bay-Estuary and Humboldt Bay.

FOOD ITEMS	Species and Location 1/ Scaup SUISB	Scaup SNPBB	Scaup HMBLT	Surf Scoter SUISB	Surf Scoter SNPBB	Surf Scoter HMBLT
Crustacea						
Isopoda			10			
Decapoda, Heptacarpus spp.			10			
Crangon nigracauda			10			18
Pyromaia tuberculata		9			15	
Unidentified crustacean fragments		18	10		5	
Mollusca						
Gastropoda, Margarites salmoneus			30			
Alvinia spp.			70			
Mitrella spp.		18	90			9
Odostomia spp.			40			
Unidentified Gastropods		18	70			9
Bivalvia, Mytilus edulis			10			
Musculus senhousia		82			40	
Clinocardium nuttali						9
Transenella spp.			70			9
Corbicula fluminea	29			13		
Tapes japonica		91			65	
Protothaca staminea			10			
Solen sicarius						73
Mya arenaria					5	
Potamocorbula spp.	79	36		73	20	
Unidentified Bivalves			20			9
Plant Material						
Scirpus spp. achenes	14	18				
Miscellaneous						
Herring (Clypea harengus) eggs		73				
Number of Birds	14	11	10	30	20	11

1/ SUISB - Suisun Bay
SNPBB - San Palo Bay
HMBLT - Humboldt Bay

APPENDIX K

Descriptive data and selenium concentrations in bird, fish, and invertebrate tissue samples. Concentrations are in ug/g (ppm) wet weight and dry weight. Size and weight are of individual birds or fish or the mean of fish in a composite sample (number in sample >1). Analyses were performed on muscle (F), liver (L), ovary (O), or whole animals (W) using hydride generation atomic absorption spectrophotometry (HGAA) at the DFG Fish and Wildlife Water Pollution Control Laboratory (WPCL).

1987-88 BIRD TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SEX	AGE	WGHT (gm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
** SPECIES GSCAUP									
* LOCATION HMBLT									
01/26/88	HMBLT	GSCAUP	M	J	920	FLESH	72	0.68	2.43
01/26/88	HMBLT	GSCAUP	M	U	1040	FLESH	73	0.81	3.00
01/26/88	HMBLT	GSCAUP	F	J	930	FLESH	72	0.94	3.36
01/26/88	HMBLT	GSCAUP	F	U	960	FLESH	72	0.80	2.86
01/26/88	HMBLT	GSCAUP	F	A	1060	FLESH	73	2.00	7.41
01/26/88	HMBLT	GSCAUP	M	J	920	LIVER	73	2.10	7.78
01/26/88	HMBLT	GSCAUP	M	U	1040	LIVER	72	2.30	8.21
01/26/88	HMBLT	GSCAUP	F	J	930	LIVER	72	2.40	8.57
01/26/88	HMBLT	GSCAUP	F	U	960	LIVER	71	2.50	8.62
01/27/88	HMBLT	GSCAUP	F	A	1060	LIVER	72	3.90	13.93
01/27/88	HMBLT	GSCAUP	M	A	900	FLESH	73	4.00	14.81
01/28/88	HMBLT	GSCAUP	M	A	900	LIVER	74	4.90	18.85
01/28/88	HMBLT	GSCAUP	F	A	930	FLESH	72	2.80	10.00
01/28/88	HMBLT	GSCAUP	F	J	680	FLESH	74	3.80	14.62
01/28/88	HMBLT	GSCAUP	F	A	930	LIVER	72	7.20	25.71
01/28/88	HMBLT	GSCAUP	F	J	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1987-88 BIRD TISSUE
SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SEX	AGE	WGHT (gm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
** SPECIES LSCAUP									
* LOCATION HMBLT									
01/27/88	HMBLT	LSCAUP	M	A	740	FLESH	72	1.10	3.93
01/27/88	HMBLT	LSCAUP	M	A	740	LIVER	70	2.90	9.67
* LOCATION SUISB									
02/23/88	SUISB	LSCAUP	M	A	940	FLESH	71	7.40	25.52
02/23/88	SUISB	LSCAUP	M	A	940	LIVER	70	31.00	103.33
03/03/88	SUISB	LSCAUP	M	J	870	FLESH	71	5.20	17.93
03/03/88	SUISB	LSCAUP	M	J	880	FLESH	71	6.80	23.45
03/03/88	SUISB	LSCAUP	M	A	650	FLESH	74	3.90	15.00
03/03/88	SUISB	LSCAUP	M	A	760	FLESH	73	9.00	33.33
03/03/88	SUISB	LSCAUP	M	A	780	FLESH	73	5.90	21.85
03/03/88	SUISB	LSCAUP	M	A	920	FLESH	73	5.80	21.48
03/03/88	SUISB	LSCAUP	M	A	860	FLESH	72	8.50	30.36
03/03/88	SUISB	LSCAUP	M	A	820	FLESH	72	6.20	22.14
03/03/88	SUISB	LSCAUP	M	A	670	FLESH	74	9.00	34.62
03/03/88	SUISB	LSCAUP	M	J	870	LIVER	72	24.00	85.71
03/03/88	SUISB	LSCAUP	M	J	880	LIVER	71	19.00	65.52
03/03/88	SUISB	LSCAUP	M	A	650	LIVER	74	9.20	35.38
03/03/88	SUISB	LSCAUP	M	A	760	LIVER	71	22.00	75.86
03/03/88	SUISB	LSCAUP	M	A	780	LIVER	72	22.00	78.57
03/03/88	SUISB	LSCAUP	M	A	920	LIVER	72	32.00	114.29
03/03/88	SUISB	LSCAUP	M	A	860	LIVER	71	30.00	103.45
03/03/88	SUISB	LSCAUP	M	A	820	LIVER	71	27.00	93.10
03/03/88	SUISB	LSCAUP	M	A	670	LIVER	72	23.00	82.14
** SPECIES RUDDYD									
* LOCATION MEYER									
02/04/88	MEYER	RUDDYD	M	U	550	FLESH	70	1.20	4.00
02/04/88	MEYER	RUDDYD	M	U	492	FLESH	74	0.45	1.73
02/04/88	MEYER	RUDDYD	M	U	548	FLESH	73	0.86	3.19
02/04/88	MEYER	RUDDYD	M	U	532	FLESH	73	0.76	2.81
02/04/88	MEYER	RUDDYD	M	U	717	FLESH	72	0.64	2.29
02/04/88	MEYER	RUDDYD	M	U	473	FLESH	72	5.10	18.21
02/04/88	MEYER	RUDDYD	M	U	454	FLESH	78	0.53	2.41
02/04/88	MEYER	RUDDYD	M	U	472	FLESH	75	0.55	2.20
02/04/88	MEYER	RUDDYD	F	U	432	FLESH	74	0.40	1.54
02/04/88	MEYER	RUDDYD	F	U	505	FLESH	74	0.57	2.19
02/04/88	MEYER	RUDDYD	M	U	550	LIVER	68	4.20	13.12
02/04/88	MEYER	RUDDYD	M	U	492	LIVER	72	1.50	5.36
02/04/88	MEYER	RUDDYD	M	U	548	LIVER	70	2.00	6.67
02/04/88	MEYER	RUDDYD	M	U	532	LIVER	72	1.70	6.07
02/04/88	MEYER	RUDDYD	M	U	717	LIVER	68	2.40	7.50
02/04/88	MEYER	RUDDYD	M	U	473	LIVER	72	17.00	60.71

1987-88 BIRD TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SEX	AGE	WGHT (gm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
02/04/88	MEYER	RUDDYD	M	U	454	LIVER	72	1.80	6.43
02/04/88	MEYER	RUDDYD	M	U	472	LIVER	74	2.00	7.69
02/04/88	MEYER	RUDDYD	F	U	432	LIVER	74	2.00	7.69
02/04/88	MEYER	RUDDYD	F	U	505	LIVER	72	1.70	6.07
* LOCATION PRYSE									
02/05/88	PRYSE	RUDDYD	M	U	585	FLESH	71	8.20	28.28
02/05/88	PRYSE	RUDDYD	M	U	543	FLESH	71	2.70	9.31
02/05/88	PRYSE	RUDDYD	F	U	485	FLESH	72	5.50	19.64
02/05/88	PRYSE	RUDDYD	F	U	442	FLESH	73	4.70	17.41
02/05/88	PRYSE	RUDDYD	F	U	561	FLESH	71	4.90	16.90
02/05/88	PRYSE	RUDDYD	F	U	501	FLESH	72	6.40	22.86
02/05/88	PRYSE	RUDDYD	F	U	462	FLESH	71	6.00	20.69
02/05/88	PRYSE	RUDDYD	F	U	535	FLESH	72	1.10	3.93
02/05/88	PRYSE	RUDDYD	F	U	450	FLESH	73	5.30	19.63
02/05/88	PRYSE	RUDDYD	F	U	401	FLESH	72	0.63	2.25
02/05/88	PRYSE	RUDDYD	M	U	585	LIVER	70	27.00	90.00
02/05/88	PRYSE	RUDDYD	M	U	543	LIVER	69	6.40	20.65
02/05/88	PRYSE	RUDDYD	F	U	485	LIVER	73	13.00	48.15
02/05/88	PRYSE	RUDDYD	F	U	442	LIVER	73	23.00	85.19
02/05/88	PRYSE	RUDDYD	F	U	561	LIVER	71	31.00	106.90
02/05/88	PRYSE	RUDDYD	F	U	501	LIVER	71	18.00	62.07
02/05/88	PRYSE	RUDDYD	F	U	462	LIVER	73	26.00	96.30
02/05/88	PRYSE	RUDDYD	F	U	535	LIVER	76	3.00	12.50
02/05/88	PRYSE	RUDDYD	F	U	450	LIVER	72	16.00	57.14
02/05/88	PRYSE	RUDDYD	F	U	401	LIVER	76	2.30	9.58
* LOCATION WFRMR									
02/02/88	WFRMR	RUDDYD	M	U	591	FLESH	73	6.30	23.33
02/02/88	WFRMR	RUDDYD	M	U	586	FLESH	72	8.20	29.29
02/02/88	WFRMR	RUDDYD	F	U	564	FLESH	72	4.60	16.43
02/02/88	WFRMR	RUDDYD	F	U	520	FLESH	72	10.00	35.71
02/02/88	WFRMR	RUDDYD	F	U	466	FLESH	71	1.60	5.52
02/02/88	WFRMR	RUDDYD	F	U	500	FLESH	73	9.30	34.44
02/02/88	WFRMR	RUDDYD	F	U	515	FLESH	73	7.10	26.30
02/02/88	WFRMR	RUDDYD	F	U	459	FLESH	74	3.90	15.00
02/02/88	WFRMR	RUDDYD	F	U	483	FLESH	72	1.80	6.43
02/02/88	WFRMR	RUDDYD	F	U	534	FLESH	74	6.30	24.23
02/02/88	WFRMR	RUDDYD	M	U	591	LIVER	72	15.00	53.57
02/02/88	WFRMR	RUDDYD	M	U	586	LIVER	74	14.00	53.85
02/02/88	WFRMR	RUDDYD	F	U	564	LIVER	72	6.40	22.86
02/02/88	WFRMR	RUDDYD	F	U	520	LIVER	72	21.00	75.00
02/02/88	WFRMR	RUDDYD	F	U	466	LIVER	71	6.90	23.79
02/02/88	WFRMR	RUDDYD	F	U	500	LIVER	73	15.00	55.56
02/02/88	WFRMR	RUDDYD	F	U	515	LIVER	74	11.00	42.31
02/02/88	WFRMR	RUDDYD	F	U	459	LIVER	73	13.00	48.15
02/02/88	WFRMR	RUDDYD	F	U	483	LIVER	73	6.50	24.07

1987-88 BIRD TISSUE
SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SEX	AGE	WGHT (gm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
02/02/88	WFRMR	RUDDYD	F	U	534	LIVER	74	12.00	46.15
* LOCATION WLAKE									
02/02/88	WLAKE	RUDDYD	M	U	472	FLESH	74	3.80	14.62
02/02/88	WLAKE	RUDDYD	M	U	436	FLESH	75	2.70	10.80
02/02/88	WLAKE	RUDDYD	M	U	485	FLESH	73	4.00	14.81
02/02/88	WLAKE	RUDDYD	M	U	564	FLESH	71	0.45	1.55
02/02/88	WLAKE	RUDDYD	M	U	504	FLESH	73	2.70	10.00
02/02/88	WLAKE	RUDDYD	M	U	464	FLESH	73	4.40	16.30
02/02/88	WLAKE	RUDDYD	M	U	517	FLESH	71	0.92	3.17
02/02/88	WLAKE	RUDDYD	F	U	543	FLESH	72	1.10	3.93
02/02/88	WLAKE	RUDDYD	F	U	511	FLESH	72	2.90	10.36
02/02/88	WLAKE	RUDDYD	F	U	580	FLESH	72	1.70	6.07
02/02/88	WLAKE	RUDDYD	M	U	472	LIVER	71	14.00	48.28
02/02/88	WLAKE	RUDDYD	M	U	436	LIVER	71	8.40	28.97
02/02/88	WLAKE	RUDDYD	M	U	485	LIVER	73	9.60	35.56
02/02/88	WLAKE	RUDDYD	M	U	564	LIVER	74	1.80	6.92
02/02/88	WLAKE	RUDDYD	M	U	504	LIVER	72	8.50	30.36
02/02/88	WLAKE	RUDDYD	M	U	464	LIVER	73	15.00	55.56
02/02/88	WLAKE	RUDDYD	M	U	517	LIVER	72	3.00	10.71
02/02/88	WLAKE	RUDDYD	F	U	543	LIVER	72	4.10	14.64
02/02/88	WLAKE	RUDDYD	F	U	511	LIVER	70	18.00	60.00
02/02/88	WLAKE	RUDDYD	F	U	580	LIVER	70	4.50	15.00
** SPECIES SCOTER									
* LOCATION HMBLT									
01/26/88	HMBLT	SCOTER	M	A	1100	FLESH	73	0.40	1.48
01/26/88	HMBLT	SCOTER	M	A	1250	FLESH	72	0.34	1.21
01/26/88	HMBLT	SCOTER	M	A	1280	FLESH	71	0.45	1.55
01/26/88	HMBLT	SCOTER	M	A	1120	FLESH	71	0.52	1.79
01/26/88	HMBLT	SCOTER	F	A	1100	FLESH	73	0.47	1.74
01/26/88	HMBLT	SCOTER	M	A	1100	LIVER	73	1.80	6.67
01/26/88	HMBLT	SCOTER	M	A	1250	LIVER	74	1.20	4.62
01/26/88	HMBLT	SCOTER	M	A	1280	LIVER	74	1.50	5.77
01/26/88	HMBLT	SCOTER	M	A	1120	LIVER	70	2.90	9.67
01/26/88	HMBLT	SCOTER	F	A	1100	LIVER	72	1.80	6.43
01/27/88	HMBLT	SCOTER	M	A	1210	FLESH	72	0.44	1.57
01/27/88	HMBLT	SCOTER	M	A	1000	FLESH	73	0.39	1.44
01/27/88	HMBLT	SCOTER	M	A	1140	FLESH	72	0.54	1.93
01/27/88	HMBLT	SCOTER	M	A	1270	FLESH	72	0.40	1.43
01/27/88	HMBLT	SCOTER	M	A	1210	LIVER	71	2.60	8.97
01/27/88	HMBLT	SCOTER	M	A	1000	LIVER	74	1.70	6.54
01/27/88	HMBLT	SCOTER	M	A	1140	LIVER	70	2.80	9.33
01/27/88	HMBLT	SCOTER	M	A	1270	LIVER	73	1.50	5.56
01/29/88	HMBLT	SCOTER	M	A	1020	FLESH	73	3.20	11.85
01/29/88	HMBLT	SCOTER	M	A	1020	LIVER	71	16.00	55.17

1987-88 BIRD TISSUE
SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SEX	AGE	WGHT (gm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
* LOCATION SNPBB									
11/16/87	SNPBB	SCOTER	M	A	1280	FLESH	72	5.50	19.64
11/16/87	SNPBB	SCOTER	M	A	1150	FLESH	73	4.20	15.56
11/16/87	SNPBB	SCOTER	M	A	1140	FLESH	74	1.60	6.15
11/16/87	SNPBB	SCOTER	M	A	1260	FLESH	73	3.20	11.85
11/16/87	SNPBB	SCOTER	M	A	1250	FLESH	73	2.80	10.37
11/16/87	SNPBB	SCOTER	M	A	1150	FLESH	73	2.80	10.37
11/16/87	SNPBB	SCOTER	M	A	1240	FLESH	72	[illegible]	[illegible]

1987-88 BIRD TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SEX	AGE	WGHT (gm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
10/21/87	SUISB	SCOTER	M	A	1100	LIVER	71	18.00	62.07
10/30/87	SUISB	SCOTER	F	J	760	FLESH	71	6.10	21.03
10/30/87	SUISB	SCOTER	F	A	940	FLESH	70	4.10	13.67
10/30/87	SUISB	SCOTER	F	J	760	LIVER	73	19.00	70.37
10/30/87	SUISB	SCOTER	F	A	940	LIVER	69	19.00	61.29
11/10/87	SUISB	SCOTER	M	A	1080	FLESH	74	1.30	5.00
11/10/87	SUISB	SCOTER	M	A	1110	FLESH	74	3.30	12.69
11/10/87	SUISB	SCOTER	M	A	1380	FLESH	72	3.60	12.86
11/10/87	SUISB	SCOTER	M	A	1200	FLESH	73	3.80	14.07
11/10/87	SUISB	SCOTER	M	A	1160	FLESH	73	5.70	21.11
11/10/87	SUISB	SCOTER	M	A	1250	FLESH	73	5.60	20.74
11/10/87	SUISB	SCOTER	M	A	1080	LIVER	69	20.00	64.52
11/10/87	SUISB	SCOTER	M	A	1110	LIVER	71	22.00	75.86
11/10/87	SUISB	SCOTER	M	A	1380	LIVER	70	36.00	120.00
11/10/87	SUISB	SCOTER	M	A	1200	LIVER	70	36.00	120.00
11/10/87	SUISB	SCOTER	M	A	1160	LIVER	69	45.00	145.16
11/10/87	SUISB	SCOTER	M	A	1250	LIVER	73	45.00	166.67
02/23/88	SUISB	SCOTER	F	J	1020	FLESH	73	5.90	21.85
02/23/88	SUISB	SCOTER	F	J	1040	FLESH	73	5.60	20.74
02/23/88	SUISB	SCOTER	F	A	1110	FLESH	74	6.10	23.46
02/23/88	SUISB	SCOTER	F	A	1025	FLESH	73	8.00	29.63
02/23/88	SUISB	SCOTER	F	A	1110	FLESH	72	4.90	17.50
02/23/88	SUISB	SCOTER	F	A	1090	FLESH	71	8.20	28.28
02/23/88	SUISB	SCOTER	F	A	980	FLESH	72	8.90	31.79
02/23/88	SUISB	SCOTER	F	A	1160	FLESH	73	10.00	37.04
02/23/88	SUISB	SCOTER	F	A	1080	FLESH	72	7.60	27.14
02/23/88	SUISB	SCOTER	F	A	1150	FLESH	74	5.80	22.31
02/23/88	SUISB	SCOTER	M	A	1120	FLESH	72	9.00	32.14
02/23/88	SUISB	SCOTER	M	A	1060	FLESH	71	9.60	33.10
02/23/88	SUISB	SCOTER	M	A	1220	FLESH	73	8.00	29.63
02/23/88	SUISB	SCOTER	M	A	1230	FLESH	72	8.80	31.43
02/23/88	SUISB	SCOTER	M	A	1340	FLESH	72	9.30	33.21
02/23/88	SUISB	SCOTER	M	A	1280	FLESH	73	7.80	28.89
02/23/88	SUISB	SCOTER	M	A	1260	FLESH	71	10.00	34.48
02/23/88	SUISB	SCOTER	M	A	1320	FLESH	72	8.20	29.29
02/23/88	SUISB	SCOTER	M	A	1120	FLESH	72	9.20	32.86
02/23/88	SUISB	SCOTER	M	A	1340	FLESH	71	9.80	33.79
02/23/88	SUISB	SCOTER	F	J	1020	LIVER	71	43.00	148.28
02/23/88	SUISB	SCOTER	F	J	1040	LIVER	72	41.00	146.43
02/23/88	SUISB	SCOTER	F	A	1110	LIVER	74	51.00	196.15
02/23/88	SUISB	SCOTER	F	A	1025	LIVER	70	54.00	180.00
02/23/88	SUISB	SCOTER	F	A	1110	LIVER	68	43.00	134.38
02/23/88	SUISB	SCOTER	F	A	1090	LIVER	70	58.00	193.33
02/23/88	SUISB	SCOTER	F	A	980	LIVER	70	71.00	236.67
02/23/88	SUISB	SCOTER	F	A	1160	LIVER	71	71.00	244.83
02/23/88	SUISB	SCOTER	F	A	1080	LIVER	74	55.00	211.54
02/23/88	SUISB	SCOTER	F	A	1150	LIVER	69	50.00	161.29

1987-88 BIRD TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SEX	AGE	WGHT (gm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
02/23/88	SUISB	SCOTER	M	A	1120	LIVER	70	61.00	203.33
02/23/88	SUISB	SCOTER	M	A	1060	LIVER	74	52.00	200.00
02/23/88	SUISB	SCOTER	M	A	1220	LIVER	72	53.00	189.29
02/23/88	SUISB	SCOTER	M	A	1230	LIVER	69	55.00	177.42
02/23/88	SUISB	SCOTER	M	A	1340	LIVER	70	62.00	206.67
02/23/88	SUISB	SCOTER	M	A	1280	LIVER	70	56.00	186.67
02/23/88	SUISB	SCOTER	M	A	1260	LIVER	70	67.00	223.33
02/23/88	SUISB	SCOTER	M	A	1320	LIVER	71	84.00	289.66
02/23/88	SUISB	SCOTER	M	A	1120	LIVER	72	45.00	160.71
02/23/88	SUISB	SCOTER	M	A	1340	LIVER	69	52.00	167.74
02/23/88	SUISB	SCOTER	F	J	1020	OVARY		15.00	
02/23/88	SUISB	SCOTER	F	J	1040	OVARY		9.80	
02/23/88	SUISB	SCOTER	F	A	1110	OVARY		14.00	
02/23/88	SUISB	SCOTER	F	A	1025	OVARY		0.00	
02/23/88	SUISB	SCOTER	F	A	1110	OVARY		10.00	
02/23/88	SUISB	SCOTER	F	A	1090	OVARY		14.00	
02/23/88	SUISB	SCOTER	F	A	980	OVARY		13.00	
02/23/88	SUISB	SCOTER	F	A	1160	OVARY		17.00	
02/23/88	SUISB	SCOTER	F	A	1080	OVARY		16.00	
02/23/88	SUISB	SCOTER	F	A	1150	OVARY		14.00	

1987-88 FISH TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SAMPLE SIZE	MEAN LENGTH (mm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
** SPECIES BRNBHD								
* LOCATION CMP13								
04/26/88	CMP13	BRNBHD	6	177	FLESH	81	0.81	4.26
04/26/88	CMP13	BRNBHD	6	177	LIVER	80	3.60	18.00
** SPECIES CHNCAT								
* LOCATION CMP13								
09/01/87	CMP13	CHNCAT	4	263	FLESH	80	1.50	7.50
09/01/87	CMP13	CHNCAT	4	310	FLESH	80	0.89	4.45
09/01/87	CMP13	CHNCAT	3	433	FLESH	80	0.88	4.40
09/01/87	CMP13	CHNCAT	4	263	LIVER	83	4.20	24.71
09/01/87	CMP13	CHNCAT	4	310	LIVER	81	4.40	23.16
09/01/87	CMP13	CHNCAT	3	433	LIVER	84	4.00	25.00
03/08/88	CMP13	CHNCAT	5	292	FLESH	78	0.90	4.09
03/08/88	CMP13	CHNCAT	5	292	FLESH	78	0.90	4.09
03/08/88	CMP13	CHNCAT	2	400	FLESH	76	0.66	2.75
03/08/88	CMP13	CHNCAT	5	292	LIVER	79	3.40	16.19
03/08/88	CMP13	CHNCAT	2	400	LIVER	79	3.40	16.19
04/26/88	CMP13	CHNCAT	6	224	FLESH	77	1.40	6.09
04/26/88	CMP13	CHNCAT	6	170	FLESH	79	1.20	5.71
04/26/88	CMP13	CHNCAT	6	170	LIVER	79	4.00	19.05
04/26/88	CMP13	CHNCAT	6	224	LIVER	78	4.00	18.18
* LOCATION MUDSL								
09/02/87	MUDSL	CHNCAT	6	218	LIVER	82	2.10	11.67
09/02/87	MUDSL	CHNCAT	5	205	FLESH	80	0.44	2.20
09/02/87	MUDSL	CHNCAT	3	250	FLESH	80	0.46	2.30
09/02/87	MUDSL	CHNCAT	5	205	LIVER	81	2.30	12.11
09/02/87	MUDSL	CHNCAT	3	250	LIVER	80	2.30	11.50
09/02/87	MUDSL	CHNCAT	6	218	FLESH	80	0.53	2.65
11/04/87	MUDSL	CHNCAT	1	280	LIVER	77	2.40	10.43
11/04/87	MUDSL	CHNCAT	1	430	FLESH	77	0.67	2.91
11/04/87	MUDSL	CHNCAT	1	430	LIVER	75	3.10	12.40
11/04/87	MUDSL	CHNCAT	1	280	FLESH	82	0.71	3.94
01/13/88	MUDSL	CHNCAT	3	405	LIVER	77	1.90	8.26
01/13/88	MUDSL	CHNCAT	3	405	FLESH	80	0.67	3.35
01/13/88	MUDSL	CHNCAT	1	550	FLESH	80	0.52	2.60
01/13/88	MUDSL	CHNCAT	1	425	FLESH	78	0.56	2.55
01/13/88	MUDSL	CHNCAT	1	550	LIVER	77	2.40	10.43
01/13/88	MUDSL	CHNCAT	1	425	LIVER	78	2.10	9.55
03/07/88	MUDSL	CHNCAT	6	354	LIVER	79	2.60	12.38
03/07/88	MUDSL	CHNCAT	6	261	FLESH	81	0.37	1.95
03/07/88	MUDSL	CHNCAT	6	272	FLESH	79	0.44	2.10
03/07/88	MUDSL	CHNCAT	6	272	LIVER	80	2.60	13.00
03/07/88	MUDSL	CHNCAT	6	354	FLESH	78	0.39	1.77

1987-88 FISH TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SAMPLE SIZE	MEAN LENGTH (mm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
03/07/88	MUDSL	CHNCAT	6	261	LIVER	80	2.50	12.50
05/02/88	MUDSL	CHNCAT	3	277	FLESH	76	0.39	1.62
05/02/88	MUDSL	CHNCAT	6	345	FLESH	77	0.39	1.70
05/02/88	MUDSL	CHNCAT	6	345	LIVER	80	2.40	12.00
05/02/88	MUDSL	CHNCAT	6	256	LIVER	80	2.10	10.50
05/02/88	MUDSL	CHNCAT	3	277	LIVER	81	1.40	7.37
05/02/88	MUDSL	CHNCAT	6	256	FLESH	78	0.31	1.41
* LOCATION SALTS								
09/03/87	SALTS	CHNCAT	4	216	FLESH	82	0.37	2.06
09/03/87	SALTS	CHNCAT	4	154	LIVER		2.30	
09/03/87	SALTS	CHNCAT	4	154	FLESH	81	0.48	2.53
09/03/87	SALTS	CHNCAT	4	216	LIVER	84	2.30	14.37
01/22/88	SALTS	CHNCAT	6	198	FLESH	82	0.28	1.56
01/22/88	SALTS	CHNCAT	5	211	FLESH	81	0.29	1.53
01/22/88	SALTS	CHNCAT	5	208	FLESH	82	0.37	2.06
01/22/88	SALTS	CHNCAT	5	211	LIVER	79	1.60	7.62
01/22/88	SALTS	CHNCAT	6	198	LIVER	86	1.70	12.14
03/09/88	SALTS	CHNCAT	5	208	LIVER	80	2.20	11.00
03/09/88	SALTS	CHNCAT	6	230	FLESH	82	0.36	2.00
04/26/88	SALTS	CHNCAT	6	230	LIVER	82	2.10	11.67
04/26/88	SALTS	CHNCAT	6	269	LIVER	78	2.10	9.55
04/26/88	SALTS	CHNCAT	6	261	FLESH	79	0.32	1.52
04/26/88	SALTS	CHNCAT	6	269	FLESH	78	0.30	1.36
04/26/88	SALTS	CHNCAT	6	261	LIVER	80	2.30	11.50
* LOCATION SJRLN								
09/02/87	SJRLN	CHNCAT	2	295	LIVER	83	1.40	8.24
09/02/87	SJRLN	CHNCAT	2	295	FLESH	80	0.21	1.05
03/08/88	SJRLN	CHNCAT	1	365	FLESH	78	0.22	1.00
03/08/88	SJRLN	CHNCAT	1	365	LIVER	77	1.70	7.39
04/27/88	SJRLN	CHNCAT	6	402	FLESH	77	0.14	0.61
04/27/88	SJRLN	CHNCAT	6	318	FLESH	77	0.16	0.70
04/27/88	SJRLN	CHNCAT	6	273	FLESH	79	0.18	0.86
04/27/88	SJRLN	CHNCAT	6	402	LIVER	81	0.98	5.16
04/27/88	SJRLN	CHNCAT	6	318	LIVER	80	1.10	5.50
04/27/88	SJRLN	CHNCAT	6	273	LIVER	79	1.30	6.19
* LOCATION SJRMR								
11/06/87	SJRMR	CHNCAT	6	248	FLESH	80	0.33	1.65
11/06/87	SJRMR	CHNCAT	6	266	FLESH	79	0.28	1.33
11/06/87	SJRMR	CHNCAT	6	248	LIVER	79	2.40	11.43
11/06/87	SJRMR	CHNCAT	6	266	LIVER	80	1.40	7.00
01/15/88	SJRMR	CHNCAT	6	240	FLESH	79	0.23	1.10
01/15/88	SJRMR	CHNCAT	6	240	LIVER	78	1.50	6.82
03/09/88	SJRMR	CHNCAT	6	275	LIVER	80	1.70	8.50
03/09/88	SJRMR	CHNCAT	6	270	FLESH	80	0.23	1.15

1987-88 FISH TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SAMPLE SIZE	MEAN LENGTH (mm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
03/09/88	SJRMR	CHNCAT	6	275	FLESH	78	0.27	1.23
03/09/88	SJRMR	CHNCAT	6	263	FLESH	79	0.25	1.19
03/09/88	SJRMR	CHNCAT	6	270	LIVER	80	1.80	9.00
03/09/88	SJRMR	CHNCAT	6	263	LIVER	79	1.80	8.57
04/29/88	SJRMR	CHNCAT	6	253	FLESH	79	0.16	0.76
04/29/88	SJRMR	CHNCAT	6	253	LIVER	82	1.40	7.78
* LOCATION MAZEB								
09/10/87	MAZEB	CHNCAT	4	271	LIVER	--		

1987-88 FISH TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SAMPLE SIZE	MEAN LENGTH (mm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
* LOCATION CLKBG								
04/18/88	CLKBG	STBASS	1	835	FLESH	77	0.47	2.04
04/25/88	CLKBG	STBASS	1	595	FLESH	75	0.33	1.32
04/25/88	CLKBG	STBASS	1	690	FLESH	77	0.44	1.91
04/25/88	CLKBG	STBASS	1	675	FLESH	78	0.41	1.86
04/25/88	CLKBG	STBASS	1	740	FLESH	78	0.37	1.68
* LOCATION SALTS								
09/03/87	SALTS	STBASS	1	230	FLESH	80	1.00	5.00
* LOCATION SJRLN								
09/02/87	SJRLN	STBASS	2	213	FLESH	78	0.26	1.18
** SPECIES WHTCAT								
* LOCATION MUDSL								
01/22/88	MUDSL	WHTCAT	1	230	LIVER	78	1.90	8.64
01/22/88	MUDSL	WHTCAT	1	230	FLESH	79	0.25	1.19
* LOCATION SALTS								
09/03/87	SALTS	WHTCAT	5	172	LIVER	82	2.70	15.00
09/03/87	SALTS	WHTCAT	5	172	FLESH	80	0.30	1.50
11/05/87	SALTS	WHTCAT	6	199	LIVER	78	2.40	10.91
11/05/87	SALTS	WHTCAT	5	171	LIVER	78	2.20	10.00
11/05/87	SALTS	WHTCAT	4	178	LIVER	79	3.40	16.19
11/05/87	SALTS	WHTCAT	6	199	FLESH	80	0.41	2.05
11/05/87	SALTS	WHTCAT	5	171	FLESH	79	0.43	2.05
11/05/87	SALTS	WHTCAT	4	178	FLESH	81	0.38	2.00
01/14/88	SALTS	WHTCAT	10	224	LIVER	78	2.60	11.82
01/14/88	SALTS	WHTCAT	10	224	FLESH	80	0.30	1.50
03/09/88	SALTS	WHTCAT	6	195	LIVER	81	3.20	16.84
03/09/88	SALTS	WHTCAT	6	172	LIVER	81	2.90	15.26
03/09/88	SALTS	WHTCAT	6	195	FLESH	81	0.38	2.00
03/09/88	SALTS	WHTCAT	6	172	FLESH	79	0.32	1.52
04/26/88	SALTS	WHTCAT	6	265	LIVER	79	2.30	10.95
04/26/88	SALTS	WHTCAT	6	265	FLESH	77	0.26	1.13
* LOCATION SJRLN								
09/02/87	SJRLN	WHTCAT	4	236	LIVER	83	1.60	9.41
09/02/87	SJRLN	WHTCAT	4	236	FLESH	79	0.14	0.67
09/02/87	SJRLN	WHTCAT	6	193	FLESH	80	0.20	1.00
09/02/87	SJRLN	WHTCAT	6	193	LIVER	83	2.10	12.35
11/03/87	SJRLN	WHTCAT	4	179	LIVER	79	1.60	7.62
11/03/87	SJRLN	WHTCAT	5	216	LIVER	80	1.00	5.00
11/03/87	SJRLN	WHTCAT	6	178	FLESH	81	0.14	0.74
11/03/87	SJRLN	WHTCAT	5	216	FLESH	81	0.10	0.53

1987-88 FISH TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SAMPLE SIZE	MEAN LENGTH (mm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
11/03/87	SJRLN	WHTCAT	6	178	LIVER	81	1.50	7.89
11/03/87	SJRLN	WHTCAT	4	179	FLESH	80	0.14	0.70
03/08/88	SJRLN	WHTCAT	4	202	LIVER	81	0.97	5.11
03/08/88	SJRLN	WHTCAT	4	202	FLESH	82	0.16	0.89
04/27/88	SJRLN	WHTCAT	5	224	FLESH	80	0.17	0.85
04/27/88	SJRLN	WHTCAT	5	224	LIVER	81	1.50	7.89
* LOCATION SJRMR								
09/10/87	SJRMR	WHTCAT	6	170	LIVER	82	2.90	16.11
09/10/87	SJRMR	WHTCAT	6	216	FLESH	79	0.25	1.19
09/10/87	SJRMR	WHTCAT	6	266	LIVER	82	2.40	13.33
09/10/87	SJRMR	WHTCAT	6	216	LIVER	82	2.70	15.00
09/10/87	SJRMR	WHTCAT	6	170	FLESH	78	0.26	1.18
09/10/87	SJRMR	WHTCAT	6	266	FLESH	80	0.20	1.00
11/06/87	SJRMR	WHTCAT	6	234	FLESH	78	0.23	1.05
11/06/87	SJRMR	WHTCAT	6	234	LIVER	78	2.10	9.55
01/15/88	SJRMR	WHTCAT	6	193	LIVER	78	1.70	7.73
01/15/88	SJRMR	WHTCAT	6	206	LIVER	78	2.00	9.09
01/15/88	SJRMR	WHTCAT	6	193	FLESH	80	0.24	1.20
01/15/88	SJRMR	WHTCAT	6	206	FLESH	80	0.24	1.20
01/15/88	SJRMR	WHTCAT	6	206	LIVER	78	1.50	6.82
01/15/88	SJRMR	WHTCAT	6	206	FLESH	78	0.25	1.14
04/29/88	SJRMR	WHTCAT	5	289	LIVER	79	1.60	7.62
04/29/88	SJRMR	WHTCAT	4	246	LIVER	82	1.60	8.89
04/29/88	SJRMR	WHTCAT	4	246	FLESH	77	0.13	0.57
04/29/88	SJRMR	WHTCAT	5	289	FLESH	76	0.14	0.58
* LOCATION MAZEB								
09/10/87	MAZEB	WHTCAT	6	199	LIVER	80	2.60	13.00
09/10/87	MAZEB	WHTCAT	6	199	FLESH	78	0.19	0.86
11/06/87	MAZEB	WHTCAT	6	217	FLESH	79	0.20	0.95
11/06/87	MAZEB	WHTCAT	6	217	LIVER	81	2.30	12.11
11/06/87	MAZEB	WHTCAT	6	196	FLESH	78	0.17	0.77
11/06/87	MAZEB	WHTCAT	6	196	LIVER	80	2.40	12.00
01/19/88	MAZEB	WHTCAT	4	220	FLESH	80	0.18	0.90
01/19/88	MAZEB	WHTCAT	4	220	LIVER	77	1.80	7.83
03/10/88	MAZEB	WHTCAT	6	247	FLESH	79	0.17	0.81
03/10/88	MAZEB	WHTCAT	6	247	LIVER	80	1.50	7.50
04/29/88	MAZEB	WHTCAT	6	253	LIVER	80	1.40	7.00
04/29/88	MAZEB	WHTCAT	6	253	FLESH	79	0.12	0.57
** SPECIES WSTRGN								
* LOCATION SNPBB								
12/28/87	SNPBB	WSTRGN	1	1365	FLESH	79	0.66	3.14
01/04/88	SNPBB	WSTRGN	1	2070	FLESH	75	0.51	2.04
01/04/88	SNPBB	WSTRGN	1	2065	FLESH	72	1.10	3.93

1987-88 FISH TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SPECIES	SAMPLE SIZE	MEAN LENGTH (mm)	TISSUE TYPE	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
01/04/88	SNPBB	WSTRGN	1	1025	FLESH	81	1.90	10.00
01/04/88	SNPBB	WSTRGN	1	1420	FLESH	77	0.99	4.30
01/04/88	SNPBB	WSTRGN	1	1510	FLESH	77	1.20	5.22
01/04/88	SNPBB	WSTRGN	1	1310	FLESH	80	0.91	4.55
01/04/88	SNPBB	WSTRGN	1	1220	FLESH	81	3.30	17.37
01/04/88	SNPBB	WSTRGN	1	1620	FLESH	76	0.65	2.71
01/04/88	SNPBB	WSTRGN	1	1430	FLESH	78	1.50	6.82
01/04/88	SNPBB	WSTRGN	1	1495	FLESH	79	1.60	7.62
01/04/88	SNPBB	WSTRGN	1	1260	FLESH	80	3.00	15.00
01/04/88	SNPBB	WSTRGN	1	1310	FLESH	81	2.00	10.53
01/04/88	SNPBB	WSTRGN	1	1200	FLESH	80	1.40	7.00

1987-88 INVERTEBRATE TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SUBSITE	SPECIES	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
** SPECIES BOATMN						
* LOCATION PRYSE						
02/03/88	PRYSE	CELL1	BOATMN	80	1.60	8.00
02/03/88	PRYSE	CELL1	BOATMN	81	2.20	11.58
* LOCATION WLAKE						
02/04/88	WLAKE	CELL4	BOATMN	85	0.86	5.73
** SPECIES BRNESH						
* LOCATION WFRMR						
02/03/88	WFRMR	CELL2	BRNESH	91	1.40	15.56
02/03/88	WFRMR	CELL2	BRNESH	91	1.40	15.56
02/03/88	WFRMR	CELL2	BRNESH	91	1.40	15.56
** SPECIES CRBCLA						
* LOCATION SUISB						
10/14/87	SUISB	ROEIS	CRBCLA	85	0.83	5.53
10/14/87	SUISB	ROEIS	CRBCLA	88	0.87	7.25
12/07/87	SUISB	ROEIS	CRBCLA	86	0.80	5.71
12/07/87	SUISB	ROEIS	CRBCLA	85	0.82	5.47
02/22/88	SUISB		CRBCLA	86	0.81	5.79
02/22/88	SUISB		CRBCLA	87	0.74	5.69
02/22/88	SUISB		CRBCLA	86	0.80	5.71
** SPECIES LTNECK						
* LOCATION HMBLT						
01/28/88	HMBLT		LTNECK	84	0.37	2.31
** SPECIES MACBAL						
* LOCATION HMBLT						
01/28/88	HMBLT		MACBAL	86	0.29	2.07
** SPECIES MACNAS						
* LOCATION HMBLT						
01/28/88	HMBLT		MACNAS	86	0.27	1.93
01/28/88	HMBLT		MACNAS	85	0.26	1.73

1987-88 INVERTEBRATE TISSUE SELENIUM LEVELS

SAMPLE DATE	SAMPLE LOCATION	SUBSITE	SPECIES	% MOISTURE	Se (ppm) wet wt.	Se (ppm) dry wt.
** SPECIES MUSSEN						
* LOCATION SNPBB						
11/23/87	SNPBB	CHCMP	MUSSEN	92	0.30	3.75
11/23/87	SNPBB	CHCMP	MUSSEN	79	0.40	1.90
11/23/87	SNPBB	WILPT	MUSSEN	78	0.18	0.82
11/23/87	SNPBB	WILPT	MUSSEN	70	0.19	0.63
11/23/87	SNPBB	CHCMP	MUSSEN	61	0.43	1.10
11/23/87	SNPBB	WILPT	MUSSEN	68	0.16	0.50
11/23/87	SNPBB	CSTCV	MUSSEN	65	0.46	1.31
11/23/87	SNPBB	CSTCV	MUSSEN	73	0.40	1.48
** SPECIES POTAMC						
* LOCATION SNPBB						
11/23/87	SNPBB	PETLR	POTAMC	54	0.47	1.02
11/23/87	SNPBB	PETLR	POTAMC	57	0.59	1.37
02/25/88	SNPBB	PETLR	POTAMC		0.67	
* LOCATION SUISB						
10/14/87	SUISB	ROEIS	POTAMC	52	0.48	1.00
12/07/87	SUISB	ROEIS	POTAMC	50	0.45	0.90
12/07/87	SUISB	ROEIS	POTAMC	53	0.43	0.91
02/22/88	SUISB		POTAMC	68	0.46	1.44
02/22/88	SUISB		POTAMC	46	0.52	0.96
02/22/88	SUISB		POTAMC	52	0.51	1.06
** SPECIES TAPESJ						
* LOCATION SNPBB						
11/23/87	SNPBB	CSTCV	TAPESJ	46	0.29	0.54
02/25/88	SNPBB	CSTCV	TAPESJ	40	0.31	0.52